Also by

R. H. WARRING

Instructions to Radio Constructors

THE Author is a design consultant and technical writer who has long had a special interest in radio. The introduction of transistors has made the construction of receivers much simpler for the amateur and in this book he concentrates on developing transistor sets from the very simplest possible types onwards. The practical work involved is well within the capabilities of anyone who is reasonably handy and a sound knowledge of radio principles will be acquired as he proceeds. Cost is not a serious difficulty, for the simplest receiver can be built for a few shillings and can be elaborated as finances permit.

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RADIO-CONTROLLED MODELS

R.H. WARRING

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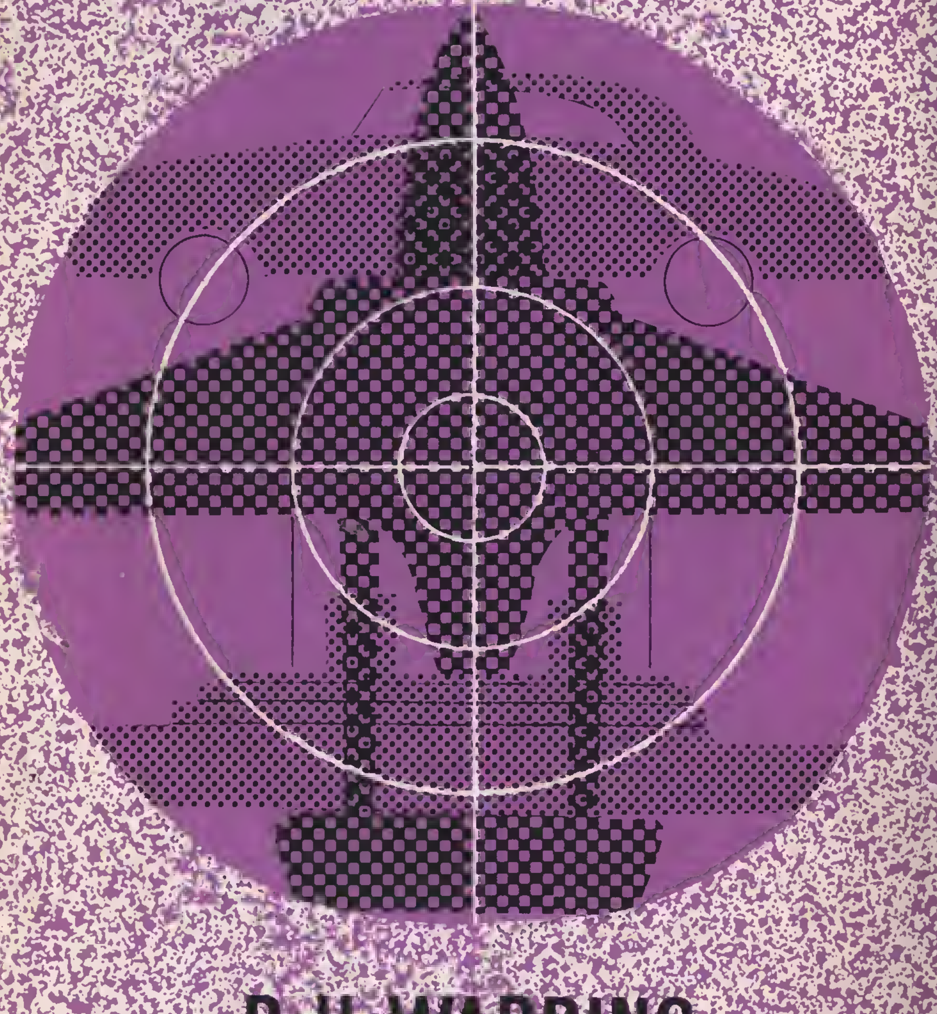

R.H. WARRING

THIS IS A COMPLETE BOOK ON RADIO CONTROL AS APPLIED TO MODEL AIRCRAFT, BOATS AND LAND VEHICLES.

It describes radio-control principles and the various methods of relating radio signals to mechanically controlled surface movements via actuators and servos. Simple single-channel systems, proportional control systems and multi-channel operation are all fully described, including installation and operation details in various types of models. In addition the various types of receivers and transmitters are explained, together with their suitability for specific control duties.

There are separate chapters on building simple radio-control transmitters from components or kits, selection of equipment, batteries, power packs, "relayless" receivers, etc.

No previous experience in radio control is assumed and the text is essentially practical in nature—hence it is the ideal manual for the beginner. At the same time the wealth of information contained makes it an invaluable reference book for the experienced modeller or radio-control enthusiast.

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RADIO-CONTROLLED MODELS

Model aircraft, boats and land vehicles

BY

R. H. WARRING

Author of Instructions to Radio Constructors, *etc.*

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PREFACE

PROBABLY to a majority of people who build and operate radio-controlled models the working of the "radio link" remains very much of a mystery. Well over 90 per cent of all radio-control modelling, in fact, is done with commercial equipment—transmitter-receiver sets and matching actuators purchased from the local model shop or specialist radio-control supplier. Practically all the contest-winning models, too, employ commercial equipment and regard the radio as something which requires "mechanical" treatment in the way of installation and adjustment.

It is due to the fact that reliable radio-control gear is readily available that this hobby-sport has commanded such a wide interest, and continues to expand in popular appeal. In the early days the radio-controlled model was unreliable, limited in performance, and more often than not a constant source of trouble to the operator—as well as frequently writing off many hours of patient work in a crash! Today it is possible to build a model aeroplane with a complete control system to duplicate full-size aircraft performance—*and* to operate it successfully without any radio knowledge. At the same time it is just as possible to get disappointing results, even with reliable equipment, by lack of knowledge of the *scope* offered by different equipment.

Rather than present a treatise on the technicalities of radio-control circuits and circuit design this book concentrates on the *practical* side of radio-controlled *models*—types of equipment, its possibilities and limitations, installation, operation, etc., and with particular reference to *system requirements* for model aircraft, boats and land vehicles. At the same time "radio" technicalities are introduced on a practical level only, sufficient to provide a background knowledge of how the transmitter-receiver link works. Such knowledge is an important part of getting the best out of any radio-control model, and a significant factor in deciding what *type* of equipment to use for a particular model.

Radio control is a fascinating hobby. It is basically an adult hobby, largely because of cost, but that does not preclude the younger enthusiast from getting in on the ground floor, as it were, with simple, home-built equipment. It is also three hobbies in one. It presents the opportunity to delve more into the mysteries of radio, if that aspect appeals, when simple proportional controls as described in Chapter 8 are an ideal starting point. It has a "model engineering" interest in devising special servo systems, actuator linkages and the like—as well as the mechanical aspects of completing a powered, working model. Finally it is the ultimate method of operating *any* working model—aircraft, boat, cars, etc.—with a satisfaction and sense of achievement that is not given by any other hobby interest.

CONTENTS

CHAPTER I

BASIC FACTS ON RADIO CONTROL

RADIO control of models appeals both to the amateur radio enthusiast as a means of experimenting in a new and still not fully developed field, and to the model enthusiast who wants to achieve the ultimate in performance with his models—remote control. The important fact is that radio control is a perfectly practical proposition in *both* cases. The electronics "expert" who can, and does build his own radio-control equipment does not have to be an experienced modeller as well. The model side can be looked after by building from a model kit, ensuring a proven design which should give him an adequate performance. Likewise the modeller, to whom electronics is very much a mystery, does not have to *know* anything about the theoretical, or even the constructional, side of radio in order to achieve perfectly satisfactory results. In this case he can regard the radio-control link simply as a switch (and the boxes housing the transmitter and receiver just "switchgear"), when installation in a model, hook-up and operation is purely a mechanical or "model engineering" job. It will be to his advantage, however, to know something of the operating principles, and particularly the scope and limitations of different types of equipment, if only to ensure that he selects the most suitable radio control units and systems for his purpose.

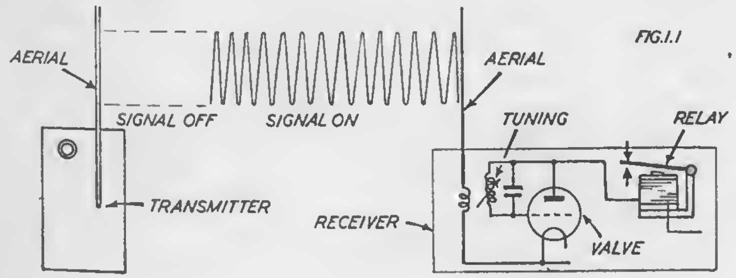
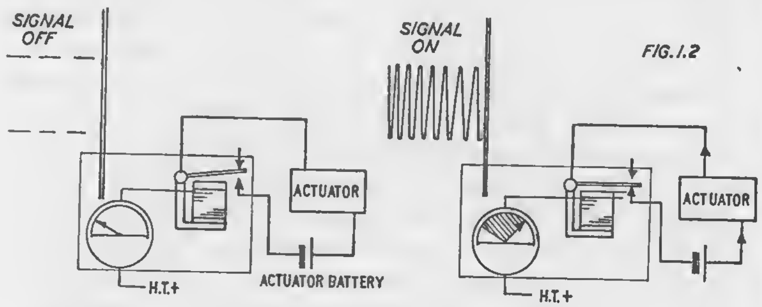
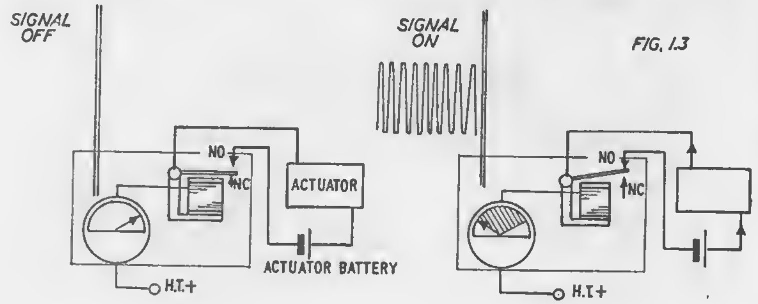


FIG.1.1

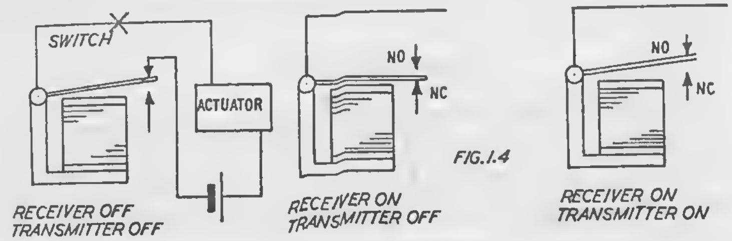
The basis of any radio-control link is as shown in Fig. 1.1. The electronic equipment comprises a transmitter and a receiver—the transmitter sending out a signal at a predetermined frequency on the operation of a control switch or button and the receiver being tuned to pick up and respond to this signal. The actual response is normally a current change through a relay. This may be a "current rise" or "current fall," depending on the design of the receiver circuit. If the receiver has "current rise" characteristics, the standing or idling current when the receiver is switched on will be low. On receipt of the transmitter signal the current will rise to some higher value. This will cause the relay armature to pull in and change its position from one contact to another (Fig. 1.2).



The electronic response in the receiver is therefore translated into a mechanical movement of a switch (the relay contacts). These, in turn, are connected to a *servo circuit* which provides the "muscle power" to move a control. Thus the relay contacts switch the servo circuit "on" and "off," in response to signals from the transmitter. With a "current rise" receiver the servo



circuit would be connected one way (i.e. to the armature and bottom or N.O. contact). With a "current fall" receiver the servo circuit would be connected to the relay armature and top contact (the N.O. contact again in this particular case) (see Fig. 1.3). "N.O." refers to the "normally open" or not-made relay contact with the receiver in the "idling" condition (not responding to transmitter signal) and "N.C." to the normally closed contact on the relay. With a "current fall" receiver it will be appreciated that a switch is needed in the actuator circuit to disconnect this circuit with receiver switched off and transmitter off (see Fig. 1.4).



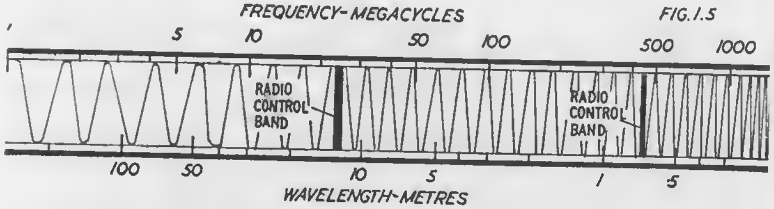
The servo circuit switched by the relay comprises an electro-mechanical device called an actuator which is energised when the servo circuit is switched on and translates this into mechanical movement. In this respect it is rather like another relay in working principle. In this case, however, energising the coil of the actuator initiates a mechanical movement powerful enough to operate a control surface on a model direct through simple linkage (see Figs. 7.1, 7.2). There are many different types of actuators (see Chapter 6) with ingenious movements to give selective control positions at will. Which type is best suited to a particular installation depends on the radio-control equipment used, and the control system required.

Types of transmitters and receivers are described in Chapter 2. These range from the simplest *single-channel* (or "single signal") sets costing about £10 or a little more for a matched transmitter and receiver, up to complex ten- or twelve-channel equipment which may cost from £75 upwards. The scope of radio-control equipment is largely dependent on price. Sets which do more, or offer specific advantages, invariably cost more. However, simple single-channel radio-control equipment

is a relatively inexpensive starting point and can be used to operate quite complex control systems. Even the absolute beginner, too, can usually achieve successful results with home-built single-channel transmitters and receivers (preferably built from kits to established, proven designs), and so reduce initial costs to a minimum (see Chapter 5).

All model radio-control equipment produced in this country has to be designed to operate within a certain frequency band. Actually there are two frequency bands allocated by the G.P.O. for model radio-control work—*26·96 to 27·28 megacycles* per second and *464 to 465 megacycles* per second (see Fig. 1.5). All (current) commercial equipment is produced

FIG. 1.5



to operate in the lower (27 megacycle) band. Sets *can* be designed and made to operate on the 464–5 megacycle band but are considerably more complex, introduce special technical problems and also difficulties in obtaining suitable components. For that reason the 464–5 megacycle band is very rarely used, even by the electronic experts. All equipment referred to in this book is assumed to be designed for, and operated on the 27 megacycle band. Certain foreign equipment available in this country may be designed to operate on 27 megacycles and a higher frequency (e.g. 52–54 megacycles), and can be operated legally only if definitely tuned to 27 megacycles. Usually this is a matter of fitting the correct tuning slug (or in some cases the tuning coil appropriate to 27 megacycle reception).

One point often overlooked is that *a licence is required* to operate radio-control equipment on either of the "free" bands. It is illegal to operate without a licence—even "bench testing" in the home—and also illegal to operate radio-control equipment outside the permitted frequency range. The necessary licence for operation is obtained simply by filling in a form

obtainable from The Radio Branch, Radio and Accommodations Department, G.P.O. Headquarters, London, E.C.1. It costs £1 and is valid for a period of five years. There are no technical qualifications required to obtain this licence, and no test to be passed (as there is when applying for a "HAM" radio licence for transmitting speech on amateur equipment).

By far the most popular application of radio control is to model aircraft, which subject also gives the most scope for remote control. With up to ten separate control "channels" or independent switching systems available on standard commercial equipment the fully controllable, fully aerobatic model aeroplane is a practical proposition. The overall cost of such a model, however, is extremely high—e.g. typically £150 for the complete radio equipment alone.

Simpler equipment, less expensive but not capable of performing the same range of independent control functions, represents limits on performance—and the safety of the model. Thus there are distinct *types* of model aircraft designed for radio control, matching different types of equipment. To use an unmatched combination—e.g. a model designed for a complete control system but operated only on limited controls—is generally asking for trouble. This subject is dealt with fully in Chapter 12.

The main point is that a model aeroplane, even when remotely controlled, is a vulnerable object. A crash, due to mishandling or a control failure, can destroy the model completely—and much of the radio-control equipment with it (although modern transistor receivers are largely "crashproof"). Thus logically one should approach the advanced type of radio-controlled model aircraft through simpler, intermediate stages with less costly models to act as "trainers." This will also provide a more satisfying background to the hobby. Even the simplest radio-control model aeroplane with just rudder control is a thrill to fly to anyone who has never tried it—and far less expensive to repair or replace during the "learning to fly" stage should it be crashed.

With model boats the position is somewhat different. Control failure, or mis-direction of the controls, is seldom damaging to the model—only inconvenient, or embarrassing. Thus absolute radio reliability is less critical; also there is far

less responsibility placed on the human "pilot" in control. Model boats, too, require less channels for complete control (see Chapter 14).

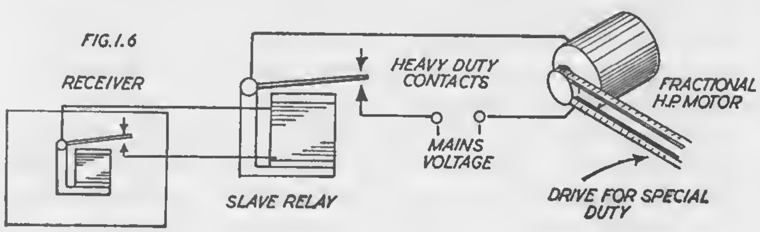
For these reasons many radio-control enthusiasts prefer boats—or turn to boats after an initial disastrous start with model aircraft. Other modellers prefer boats to aircraft in any case, and fitting radio control offers tremendous scope. It is not limited to steering and controlling power-boats but can also be applied to the remote control of sailing yachts (steering *and* adjusting the sheets and trim).

Model cars and land vehicles are another possible subject for radio control, although perhaps rather more limited in scope. However, with steering and speed controls (including reverse, which is readily possible with electric motor drives), this type of model forms the ideal subject for "backyard" use. The model aeroplane needs its flying field, the model boat its pond. The radio-controlled vehicle can be operated on the lawn, or even in the sitting-room. Here again control failure is "non-critical" and a model, once complete, should stay serviceable for years.

Although designed specifically for model control systems, standard transmitter-receiver combinations are equally suitable for other forms of radio control. Model equipment, in fact, has been designed to operate garage doors (opening or shutting them on receipt of a signal from a transmitter in the approaching car); control a powered lawnmower; operate sun blinds by remote control; and so on. Descriptions of these possible applications are outside the scope of this present book, but are mentioned as a matter of interest.

The control circuit, in such cases, usually works on much higher voltages and currents—it requires a fairly large electric

FIG. 1.6



motor operating off mains voltage to open a garage door, for example. In consequence, the standard receiver relay cannot be used directly for controlling the servo circuit since the contact would not stand up to the current which would have to flow through them. Instead the receiver relay is connected to a larger, more robust relay, called a "slave" relay, as in Fig. 1.6. The contacts on this slave relay are heavy enough to carry the required current and so successfully switch the final servo circuit. Slave relays are also used in some model radio-control circuits where the current to be switched by the receiver is heavier than the receiver relay contacts can stand.

CHAPTER 2

RADIO-CONTROL EQUIPMENT

THE simplest type of radio-control link employs a carrier wave (CW) transmitter and single-valve receiver of the super-regenerative type. The principle involved in this case is that the transmitter is capable of sending a smooth, continuous radio frequency (RF) signal when its control switch is operated (Fig. 1.1). The receiver when switched on "idles" at some high current value and thus the relay is pulled in. On receipt of signal the current falls to some lower value, permitting the relay armature to drop out. Thus the receiver operates on the "current fall" principle (see Figs. 1.3 and 1.4).

The actual current change is usually quite small and depends on the circuit design and the high-tension voltage. Thus, typically, from an idling current of 3 to 4 milliamps, the current may fall to around 1·5 milliamps on receipt of signal. The current change in this case of the order of 1·5 to 2·5 milliamps, and an extremely sensitive relay has to be employed to respond to this change. Also relay adjustment is a matter of considerable importance.

Most of the earlier commercial sets and circuit designs worked on this principle and "carrier" equipment, as it is usually called (the Americans call it "CW" or continuous wave), is still widely employed. It is particularly suited to home construction since it employs simple circuitry and a minimum of components.

One limitation is that to obtain a reasonably high current change a fairly high HT battery voltage is usually employed—e.g. 60 volts or even 90 volts. All the time the receiver is switched on it draws maximum current and thus battery life is fairly short and requires frequent replacement. This can be overcome in a simple manner by "reversing" the operation. The transmitter switching is so arranged that when switched on but *not* keyed it sends out its CW transmission.

Normally a transmitter has two switches—an on-off switch which switches the batteries into circuit, and a keying switch which causes the CW transmission to be radiated. When the receiver is switched on it is influenced by the carrier signal and therefore reverts to minimum current condition. Operating the transmitter keying switch to transmit a signal then switches the CW transmission *off*, causing the receiver current to *rise*.

Just by modifying connections on the transmitter, therefore, the receiver is now operating as a "current rise" type, with considerable economy as regards receiver batteries. Note in this case, however, the "make" contact for the servo circuit now becomes the front contact of the relay (Fig. 2.1) and no separate switch is necessary to switch the actuator circuit off when not in use.

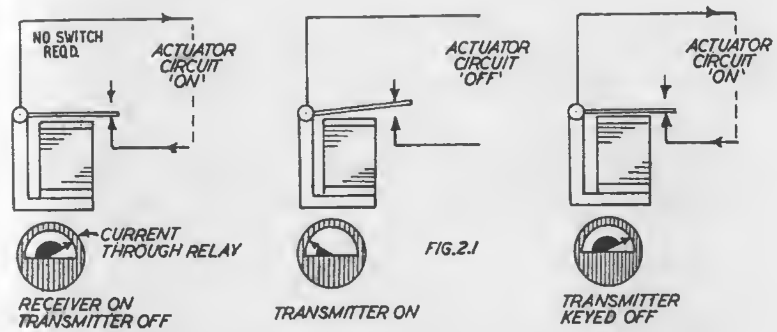


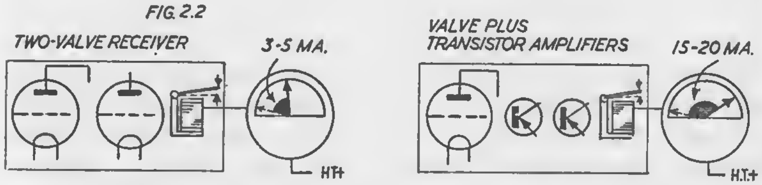
FIG. 2.1

The gain in life of receiver batteries is obtained at the expense of the transmitter batteries. This is justified as the transmitter batteries are usually larger and capable of withstanding continuous drain, especially in the case of a ground-standing transmitter. With the smaller high-voltage batteries used in hand-held transmitters, however, the saving is less apparent. A more modern receiver circuit design working on the "current rise" principle is usually to be preferred.

"Current rise" charactcristics can be given by a two-valve circuit (or valve plus transistor amplification). Such receivers normally have a very low idling current. On receipt of signal the current in the first valve falls to virtually zero, which biascs off or "triggers" the second valve resulting in the current

in the relay circuit rising to some high figure—typically 3 to 5 milliamps with valve receivers and 15–20 milliamps with a valve followed by transistor amplifiers (Fig. 2.2). Such a receiver is generally more reliable in operation and renders relay adjustment less critical, compared with single-valve receivers.

FIG. 2.2



The alternative to "carrier" operation is "tone," which offers further advantages. The transmitter in this case is designed to transmit a continuous carrier wave at radio frequency (RF) but operation of the keying switch superimposes a lower frequency (AF) signal or "tone" to modulate the carrier signal (Fig. 2.3). The receiver circuit in this case

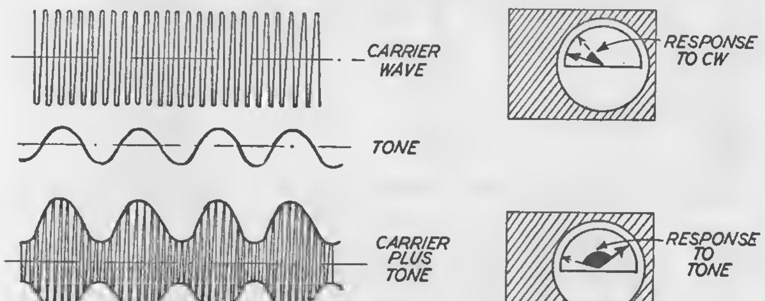


FIG. 2.3

is designed to "tune in" to the carrier signal and *respond* to the tone signal, as transmitted. This is exactly the same in principle to a domestic radio being tuned in to a broadcast station. The radio is tuned in to the station but nothing happens when the microphone in the studio is switched off. When the programme starts and the microphone is switched into the transmitter circuit, speech or music is heard via the receiver loudspeaker. In the case of the "tone" radio-control set, transmission of "tone" by the transmitter is picked up by the receiver and translated in terms of current change.

Typical response with a "tone" receiver is that when switched on it will idle at a fairly low and relatively unsteady current. On the transmitter *carrier* being switched on (and assuming the receiver is correctly tuned), the current in the receiver will drop to some steady low value approaching zero. On receipt of the "tone modulated" signal superimposed on the carrier the current will then rise to a maximum value.

All tone receivers, therefore, operate on the "current rise" principle, usually with a large current change so that relay operation is even more reliable. The resulting circuit is inevitably more complex, and more expensive, but lends itself particularly well to the employment of transistors instead of valves (although a conventional valve may still be retained for the detector stage). This means that only small, inexpensive batteries are required, resulting in economic operation.

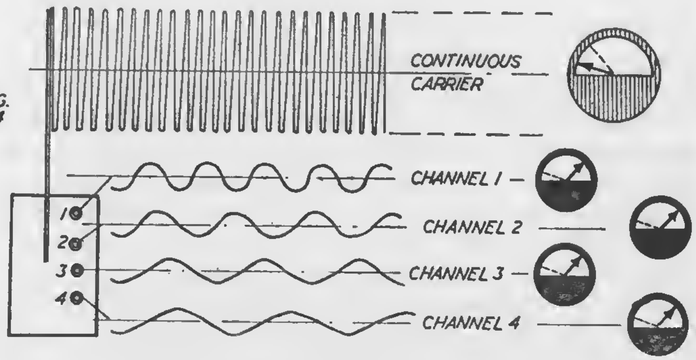
There are other advantages with "tone" receivers, too. Since the RF signal is being received all the time this tends to desensitise the receiver and make it less susceptible to interference from other "spurious" signals and "noise" (the latter referring to interference generated by electric motors or other equipment in the model itself). Also the *strength* of the carrier wave is not so important, so that a tone receiver will operate at satisfactory range on a lower power transmitter (compared with a CW receiver).

This is particularly significant since the trend is towards the use of hand-held transmitters almost exclusively for model radio control (and particularly aircraft), because of their more convenient size and weight. Hand-held transmitters are less efficient than ground-standing transmitters, and usually have a lower power input and much lower power output. As a result range tends to be reduced (particularly with CW operation). The "tone" transmitter-receiver combination is far less affected in this respect than "carrier" equipment and "tone" receivers almost invariably offer the best performance with hand-held transmitters.

The "tone" transmitter-receiver combination is also the most popular choice for "multi" control operation. In both cases so far considered the receiver is capable of identifying and responding to a single signal—and hence is referred to as a "single-channel" type. It is a comparatively straightforward

process—although it calls for a more complicated circuit—to arrange for the transmitter to superimpose a number of *different* tones at will (i.e. each controlled by a separate switch) on the carrier wave. The receiver circuit can be correspondingly designed to identify and respond to *each* of these tones separately (Fig. 2.4).

FIG. 2.4



The number of separate tones determines the number of individual signals or "channels" available. Thus multi-channel equipment may comprise "two-channel," "three-channel," etc., up to a practical maximum of about twelve-channel. Each "channel" available means that one particular control action may be switched independently, and with some types of multi-channel equipment it is possible to signal two separate channels simultaneously. Multi-channel principles and operation are covered in Chapters 9, 10 and 11.

Multi-channel equipment does not necessarily have to operate on "multi-tone" signalling basis, although this is the usual method. Equally, multi-*operation* of controls does not necessarily depend on the use of multi-channel equipment. Separate, individual control actions can be given with single-channel equipment by using a suitable actuator to select individual control services in sequence (see Chapter 6).

This, in fact, is the basic difference between "multi-channel" and multi-control systems operated by single-channel equipment. The former gives immediate, independent selection of a particular control service required. The latter can provide almost as many services, but has to select any particular service

by switching through a *sequence* of separate control positions; or employ a system of "pulsing" or otherwise modifying the transmitter signal to provide a more complex control response. The scope and application of these different methods are discussed in later chapters.

As a general guide, *simple single-channel* operation is virtually restricted in practice to one control surface movement (e.g. rudder), plus one further control service (e.g. engine control) on aircraft. This is the equivalent of "three-channel" operation but is slower than *direct* three-channel signalling. Any further complication by trying to introduce further control services through sequence switching usually results in too much delay for maintaining control of the model, and the possibility of "losing" the required control at a critical moment.

More complex switching, via special actuators, may be quite satisfactory in a boat where operating conditions are far less critical—and there is ample time to recover loss of sequence.

Multi-channel equipment provides the logical solution where more than one separate control service is required on any model—although it is inevitably more expensive than single-channel systems. Multi-channel is the only real solution for operating more than rudder and elevator controls on an aircraft with any degree of safety. The more sophisticated "pulsed" single-channel systems do, however, provide an inexpensive alternative, albeit with definite limitations.

Given good circuit designs and sound construction the weakest link in the radio-control chain is then likely to be the batteries. Particularly in aircraft, where weight and space is at a premium, the smallest sizes of dry batteries tend to be employed. The life of such batteries is relatively short and unless replaced frequently (which is costly) can lead to radio failure (see Chapter 16). The same is also true of transmitter batteries, particularly those used in hand-held transmitters where quite high current drains are usual.

The fully transistorised circuit economises on batteries by working on much lower voltage, with a single battery replacing the conventional high-tension (HT) and low-tension (LT) batteries required for valve circuits. It is only comparatively recently that suitable transistors have become

available for use in the detector stage of the receiver but the fully transistorised receiver is now an accepted and reliable unit. The fully transistorised transmitter, on the other hand, has still (1962) to be developed to the stage where it can compare in reliability and performance with a transmitter employing valve circuits. Hence the usual transmitter requires high-voltage batteries, or at least a high-voltage (HT) supply.

It is possible to supply this HT voltage (and the necessary LT voltage) from a low-voltage battery (accumulator) via a convertor. Rotary convertors are particularly suitable but are heavy and bulky. Their application is therefore limited to fitting into ground-standing transmitters. They also draw high current, necessitating coupling to a fairly substantial accumulator (typically a car battery).

Using transistor amplifying circuits, however, it is perfectly practical to provide the necessary HT supply from quite a small accumulator (e.g. a DEAC battery) in a unit comparable in size with the smallest dry battery of similar voltage. The LT voltage can also be tapped off the convertor to form a complete power pack to replace both dry batteries normally required. Such power-packs, as they are called, are produced to fit in a hand-held transmitter case together with the appropriate accumulator; or in the form of a complete, sealed pack which includes the accumulator. The great advantage in using such an accumulator-type power-pack is that the accumulator can be re-charged as necessary and thus *no* battery replacements are called for.

Power-packs are also made for supplying receiver circuits. These are usually even smaller and can provide the complete battery complement required—high-tension and low-tension (filament) supply for the receiver *and* the necessary voltage for the servo circuit (Fig. 2.5).

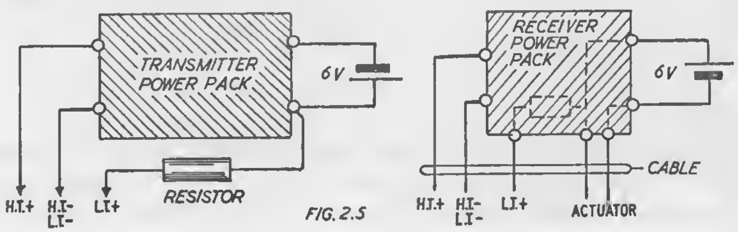


FIG. 2.5

CHAPTER 3

TRANSMITTERS

Two basic types of carrier-wave transmitter are shown in block diagram form in Fig. 3.1. In its simplest form the circuit is amazingly simple, with a minimum of components, and consists only of a single valve oscillator circuit feeding the aerial. Many circuits of this type are in use and are produced commercially.

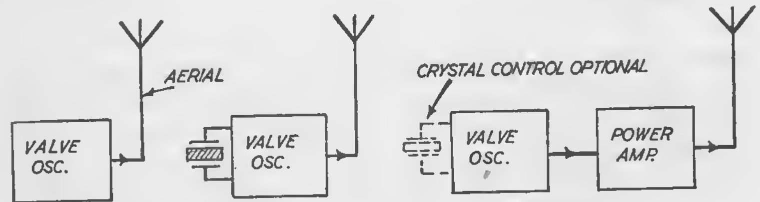


FIG. 3.1

The chief limitation with this type is that for adequate performance the valve has to be driven hard, drawing relatively high current (e.g. 18–20 milliamps) and "peaked" or nearly peaked for maximum signal strength. Thus tuning is quite critical and the circuit is susceptible to detuning or variation in output with differences in ground coupling (proximity of the transmitter to the ground), hand capacity, the dryness of the ground (in the case of ground-standing transmitters), and so on. Also tuning will be affected by mechanical disturbances due to vibration, knocks, etc. Actual stability achieved is very much dependent on the circuit used, and the mechanical design of the components. Ultimate performance, too, is very dependent on the use of an efficient aerial and efficient aerial coupling, and the circumstances in which the equipment is used.

An inherently more stable arrangement is provided by using one valve as an oscillator and another to provide RF amplification. This combination of master oscillator plus power

amplifier is generally referred to as a MOPA-type transmitter. This is rather more wasteful of power input in that the power absorbed by the first valve is not directly fed to the aerial, but the amplifier stage connected to the aerial is generally more efficient than direct coupling of the oscillator to the aerial.

In appearance the MOPA transmitter may seem to have only one valve since both the oscillator valve and amplifier valve may be contained in a single envelope (a 3A5 or DCC90 is a popular choice), thus offering a simple form of construction. This circuit gains in enabling the oscillator to draw a relatively low current (e.g. 8–10 milliamps) and operate under more stable conditions, with the final output boosted by the amplifier. Final tuning on the amplifier stage can be peaked out without causing trouble.

A tone receiver requires the addition of at least one more valve to act as an audio-frequency oscillator (AF oscillator) to generate the tone. The "tone" signal may be fed into a single-valve oscillator although again the MOPA circuit is generally much easier to modulate with tone and is usually favoured on modern transmitters (see Fig. 3.2).

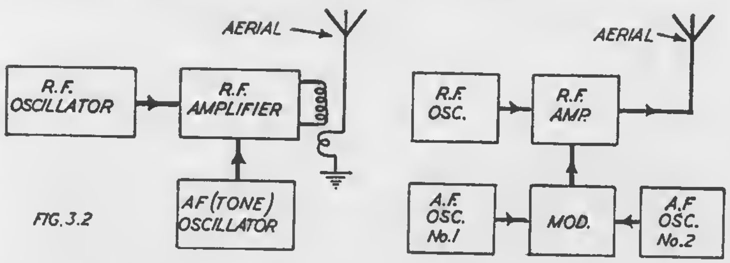


FIG. 3.2

With carrier-wave signals the RF signal consists of a wave-form oscillating at 27 megacycles (27,000,000 cycles) per second. The tone signals used to modulate this carrier-wave for "tone" transmission are of very much lower frequency within the audio range (hence AF or audio-frequency). The audio frequencies used may vary from anything between 300 cycles per second to 6,000 cycles per second or more, depending on the designer's preference, the type of equipment, the amount of separation needed for multi-channel signalling, and so on. The 300–600 cycle range is usually favoured for single-channel tone receivers.

There is also the question of the *amount* of modulation produced by superimposing this AF on the RF carrier. This is usually expressed as a percentage. Thus 50 per cent modulation results in a final wave form or modulated signal like that shown in Fig. 3.3. If the AF modulating signal is larger a

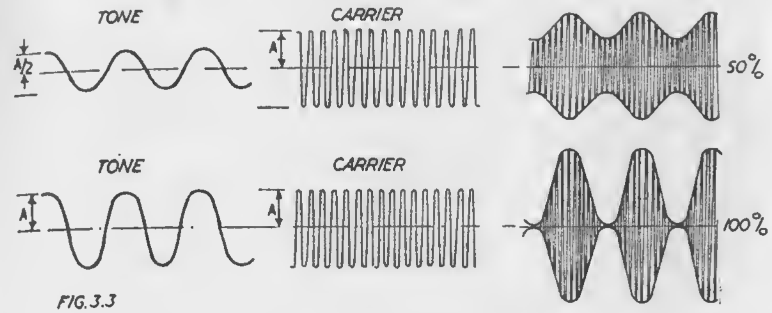


FIG. 3.3

higher degree of modulation is obtained, up to 100 per cent. It is possible to produce more than 100 per cent modulation but this results in actual breaks in the carrier itself and is theoretically bad. Most modulated tone equipment is designed to operate on anything between 85 and 100 per cent modulation but a majority designed for a nominal 80–85 per cent modulation do, in fact, exceed 100 per cent modulation on working.

For multi-channel operation the AF circuit can be designed to provide a number of different tones, any one of which can be fed into the basic circuit at will to modulate the RF signal accordingly (see Fig. 2.4). Where simultaneous operation is required two (or more) separate tone generators will be required. Simultaneous operation is normally restricted to eight-, ten- or twelve-channel equipment, offering simultaneous operation on two selected "banks" of controls, i.e. using two separate tone generators (see Fig. 3.2). This is standard practice with multi-channel reed receivers (see Chapter 10).

Any transmitter—which is basically an oscillator—is capable of being tuned over a range of oscillating (transmitting) frequencies. To comply with regulations it must be adjusted to radiate within the correct frequency band. Commercial transmitters are factory-tuned and pre-set to the correct

frequency and therefore need no adjustment. They are assumed stable enough in design to stay within the correct frequency when standard practice is always to tune a *receiver* to a given transmitter.

Where home-built equipment has to be set up, however, there is no indication that the transmitter is on frequency even if a standard receiver can be tuned to respond to it. The tuning range of most receivers is usually sufficiently broad to respond to signals on either side of the permitted frequency. It therefore becomes strictly necessary to be able to check transmitter frequency with non-crystal-controlled types.

This can be done by tuning the transmitter against a calibrated wavemeter; or alternatively *to* a *superhet* receiver which is known to be tuned to respond to a signal within the permitted frequency. In the former case a calibrated instrument is required. An absorption wavemeter is quite easy to construct (see Fig. 3.4) but still needs to be *calibrated* before it can be

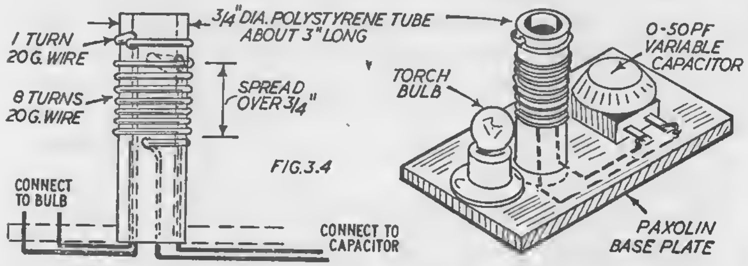


FIG. 3.4

used. The method sometimes recommended for tuning a home-built transmitter against a conventional super-regenerative receiver "on tune" to another transmitter *known* to be on frequency is *not* reliable. Super-regen. receivers have such broad tuning (see Chapter 4 and Fig. 4.1) that there is no guarantee that this method can fix the transmitter frequency within the permitted band. A further receiver tuned to it may then be operating well off the legal frequency.

This tuning affects only the oscillator circuit, normally tuned by adjustment of a variable capacitor. On a MOPA circuit there will usually be a second trimmer or tuner for the amplifier stage to be adjusted for maximum signal strength (e.g. maximum reading as indicated by a field strength meter or tuning

indicator light incorporated in the circuit). There may be some interaction between stages so that tuning of the second stage may affect the first, requiring a repeat of adjustments. Some transmitter circuits, both single-valve and MOPA, may also have a further trimmer to adjust on the aerial coupling.

Tuning troubles and frequency drift can virtually be eliminated on transmitters by employing *crystal control.* A crystal is simply a RF component which has a natural frequency of oscillation. If incorporated in the oscillator circuit or output it will permit the circuit to oscillate only at the predetermined frequency. Crystal control is obligatory on all radio-control transmitters in the United States, but not in this country. Because it means additional cost both manufacturers and designers of "do-it-yourself" circuits have tended to avoid crystal control, although it is now becoming more commonplace.

The crystal employed may be a sub-harmonic of the required output frequency (usually one-half or one-third of the frequency required). Often a third overtone crystal is employed which, although it has the geometry of a 9-megacycle crystal will oscillate at $3 \times 9 = 27$ megacycles in the circuit. It can thus be used directly to control the frequency of the RF oscillator.

Where the crystal frequency is one half the required output frequency then frequency doubling is carried out in the transmitter circuit—either in the anode circuit of the oscillator stage and then fed to a 27-megacycle power amplifier; or the output of the oscillator stage is 27/2 megacycles to drive a frequency doubled in the power-amplifier stage (see Fig. 3.5).

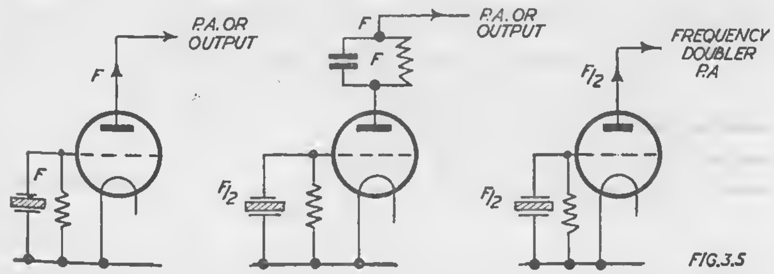


FIG. 3.5

The power of radio-control transmitters is limited to a maximum of 5 watts input under the G.P.O. regulations.

The actual efficiency of a transmitter varies widely with different types and different circuits—typical figures ranging from as low as 10 per cent upwards, with 30 per cent an exceptionally high figure. The obvious approach would appear to be to use as high an input power as permitted to ensure maximum output power, and thus maximum signal strength and range. This was, originally, the approach with early ground-standing transmitters and CW receivers, bulk and weight of the transmitter batteries or power-pack being considered relatively unimportant.

It is virtually impossible to consider high-power input figures of this order with hand-held transmitters, however, without prohibitive battery drain—nor is it necessary. The average power input of most transmitters today is of the order of 1·5 to 2 watts maximum, and in many cases is much lower. This is particularly true of "tone" equipment and superhet receivers where high signal strengths are not so necessary and many lightweight transmitters operate successfully at very low input power. Range does, however, tend to be restricted with low input power unless particular attention is given to realising a high overall efficiency.

This, largely, boils down to a good aerial system. The ground-standing transmitter normally employs an 8–9 feet aerial and with more efficient ground coupling because of its proximity to the ground. The hand-held transmitter normally employs a telescopic aerial (for neatness and portability) with a restricted extended length (usually about 48 inches) (Fig. 3.6).

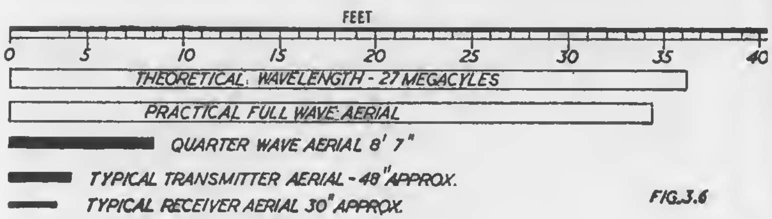


FIG. 3.6

Aerial coupling is then an important feature of the performance, particularly as telescopic aerials, as such, tend to be relatively inefficient. Expediencies such as centre-loading coils are sometimes incorporated in the aerial (equivalent to increasing the effective aerial length) to improve aerial efficiency and/or compensate for a low-power input. Without such an artificial extension of aerial length the transmitter range may be too short to be of practical use in controlling a model aircraft, although it might be quite sufficient for controlling a boat or land vehicle.

"Tone" equipment benefits from not requiring such a high signal strength, as previously described, so the conventional moderate to low power transmitter with telescopic aerial is perfectly satisfactory with good circuit design and construction, and correct tuning. Superhet receivers are even better because of their extreme selectivity (see Chapter 4). A crystal-controlled transmitter is also better than a non-crystal-controlled one at range since optimum tuning is more precise and there is absence of scatter over a broader range of frequency to reduce the effective transmitter signal strength.

The question of the range of a particular transmitter is purely arbitrary. Any transmitter has, theoretically at least, an infinite range, with the signal strength decreasing as the square of the distance. The range of any particular transmitter can only be determined *relative to a particular receiver*. An extremely sensitive receiver may respond to a low-power and relatively inefficient transmitter at, say, 300 yards. A poor receiver, on the other hand, may not respond to a powerful, efficient transmitter at 100 yards. Reverse the receiver-transmitter combinations and the respective ranges may be 5 yards and 2 miles. One could not claim a range of 300 yards as typical of the low-power transmitter or 100 yards as typical of the high-power transmitter! Range can only be quoted—or determined—with any meaning relative to particular transmitter-receiver combinations.

Working range is also affected by operating conditions. Ground-to-ground range (i.e. transmitter at ground level and receiver in the model at ground level) is less than ground-to-air range—the latter condition typical of a model aeroplane in flight. In this case the effective range may be trebled, compared with ground-to-ground range found by test. Certainly it will be much higher than the apparent range established by ground-to-ground checks.

Other conditions will affect range—see also Chapter 16. The proximity of overhead wires, metal buildings, etc., will tend to distort the transmitter signal and affect possibly both range and tuning. Receiver tuning in a model boat will also be different out of the water and with the model afloat. Then there is also the chance of detuning a critically stable transmitter merely by moving it or by movement of the keying lead connecting to a ground-standing unit.

A field-strength meter can be used to check range, and signal strength for any given transmitter. As normally used, however, a simple field-strength meter does not provide *accurate* measurement of output. For correct measurement it needs to be at least ten wavelengths away from the transmitter. The wavelength corresponding to a frequency of 27 megacycles is roughly 33 feet, meaning that for accurate reading with a field-strength meter the distance between transmitter and meter would have to be at least 330 feet, or well over 100 yards. Field-strength meters are normally used quite close to the transmitter and at best, therefore, can only give *comparative* figures between the performance of one transmitter and another. A similar form of comparative check can be done with a receiver with the transmitter aerial retracted (or partially retracted) (see Chapter 16).

Usable range is another matter. For relatively close distance operation, as is usual with model boats, etc., the required range is determined by the available size of the pond. With model aircraft in flight there is virtually unlimited distance available. Once the model has travelled about a quarter of a mile from the operator, however, it will be difficult to control for it cannot clearly be seen which way it is heading. Hence it is difficult to keep it under control—and all too easy to turn it the wrong way and so make things even worse. The *usable* range, therefore, is that distance over which the eye can follow faithfully the direction and attitude of the model in flight—and this is quite a moderate figure. An effective ground-to-ground range check of 300 yards is usually perfectly satisfactory to ensure complete and adequate range for flying.

CHAPTER 4

RECEIVERS

THE basic operating principles of the radio-control receiver have already been explained in Chapter 2. They may be grouped, specifically, as "carrier" or "tone" type, depending on whether they respond to carrier-wave (CW) or modulated-tone signals, respectively. Any carrier-wave transmitter will operate any CW receiver. Tone transmitters which switch the CW component of the signal separately may be used to operate CW receivers—i.e. usually switching the transmitter on and off switches the carrier "on" and "off" and thus can be used for signalling via the carrier transmission, provided the particular circuit has negligible "warm-up" time. Some "tone" transmitters, however, switch carrier and tone simultaneously to economise on battery drain and in this form are not suitable for CW signalling.

It does not follow that any tone transmitter can be used with any tone receiver. It may not be possible, for instance, to tune the AF component to the receiver frequency; or the degree of modulation achieved by the transmitter may not suit a particular receiver. Most tone transmitters of orthodox design will, however, match orthodox tone receivers, although the more usual practice is to employ matched sets (e.g. transmitter and receiver of matched design or manufacture).

The reliability of a receiver depends largely on its sensitivity, stability and current change. *Selectivity* or the ability to pick up radio signals of a particular frequency is seldom a problem with super-regenerative circuits. In fact, tuning tends to be quite broad. This also represents a distinct limitation in that when tuned to a particular (transmitter) frequency the receiver may also respond to other spurious signals over a fairly wide frequency band.

For this reason it is normally impossible to operate more than one super-regen. receiver simultaneously within the

permitted 27 megacycle frequency band. Even if the two transmitters are sharply tuned to different frequencies within the band (e.g. using crystal control with separate frequencies within the band), any one receiver will pick up signals from both transmitters. This position is further aggravated by the fact that certain types of super-regen. receivers do tend themselves to act as transmitters (particularly when adjusted to maximum sensitivity) and could interfere with other receivers operating nearby.

This limitation of "broad" tuning is overcome with the super-heterodyne receiver which can be made extremely selective (Fig. 4.1). Tuning is so sharp that anything up to six

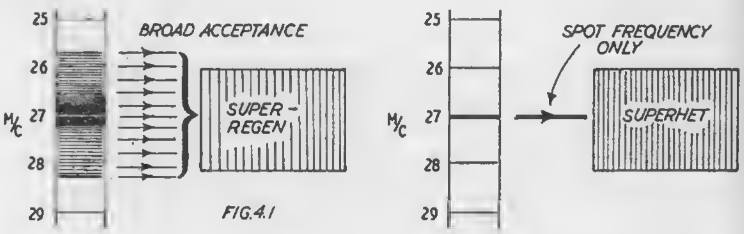


FIG.4.1

different receivers may be operated simultaneously within the 27-megacycle band (each tuned to a different "spot" frequency differing by 50 kilocycles) without interaction between them. The only real disadvantage with the superhet. is that the circuit is considerably more complicated and more difficult to set up.

Basically the superhet. and super-regen. receiver differ only in respect to the "front end." The superhet. also needs to be crystal-controlled to ensure its own freedom from drift. A typical approach is to design a superhet. "front end" adaptable to replace the RF section of a conventional super-regen. receiver. The increased cost of such a receiver tends to limit its scope as a popular production item, and its increased complexity its scope for home-construction, but it has become an established type both for single-channel and multi-channel work.

The *sensitivity* of a receiver means its ability to pick up and respond to weak signals. Sensitivity, therefore, largely determines the range of a particular receiver used with a particular

transmitter (Fig. 4.2). The lower the power of the transmitter the greater the sensitivity required from the receiver to achieve the required range.

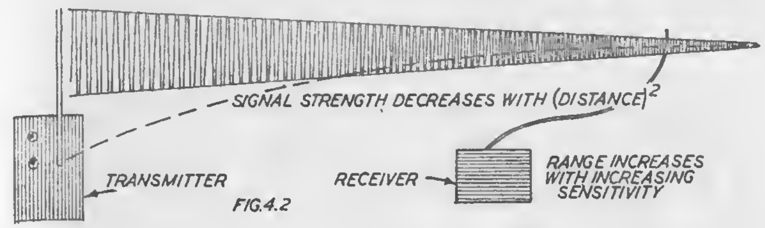


FIG.4.2

Too great a sensitivity is not desirable since this means that the receiver may equally well respond to stray signals and "noise"—and even be impossible to operate in a model which employs electric motors for servo power. Extreme sensitivity, too, may mean critical stability—so sensitivity and stability are closely linked.

An unstable receiver is one which goes in and out of oscillation, causing "skipping" of the controls. A similar result can develop through interference or inadequate sensitivity (lack of range) and it is not always easy to determine which is the true cause.

In the case of receivers employing a sensitivity control as well as a tuning control, adjustment of the former must aim at a suitable compromise between range and stability. Typical procedure is to back off the sensitivity control from the critical position (i.e. the setting which just holds a steady idling current), tune to the transmitter signal on the tuning control and then re-check the sensitivity setting as being backed off the specified amount.

The current change achieved with the receiver largely determines its reliability. The greater the current change the less critical the relay operation becomes and the less critical the relay adjustment. Many earlier designs worked on a current change of 1·3 milliamps, or even less. This called for the use of an extremely sensitive relay and very precise adjustment. Within the limitations of a simple single-valve circuit a greater change can only be produced by an increase in HT battery voltage, resulting in a more expensive set to operate.

The basis of relay adjustment is shown in Fig. 4.3. Assuming a receiver with "current fall" characteristics, the relay armature position is adjusted by altering the back contact (screw adjustment or by bending the contact, according to whether the relay has adjustable or fixed contacts) to pull in at some

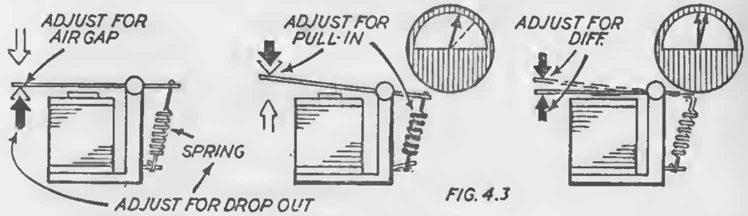


FIG. 4.3

figure below the normal standing current. The "pull-in" current chosen would normally be just above the middle of the current change range. This allows for the top current to fall off slightly and still give a margin of extra current to hold the relay in.

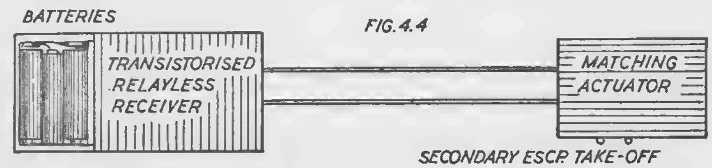
The bottom contact of the relay is then adjusted so that the relay armature will "drop out" or release at a current value a little below the "pull-in" value. The difference between "pull-in" and "drop-out" current is known as the differential and would normally be quite small. To achieve satisfactory "pull-in" and "drop-out" current values, together with a suitable differential, may require several "trial and error" adjustments of the contacts, and also alteration of the spring tension. The armature must *never* be allowed to touch the pole piece when pulled in, otherwise residual magnetism will tend to hold it in and delay "drop-out."

It will be appreciated that with "current-fall" operation of the receiver the usable contacts (for servo-circuit switching) are "made" under spring pressure. Hence the desirability of locating the "pull-in" current as high as possible (enabling a good spring pressure to be employed), with a close differential. With a "current-rise" receiver the switching contacts are made by the relay pulling in—favouring a lower "pull-in" current to provide a good margin of excess current to hold the relay in. The differential again needs to be quite close, otherwise the spring tension may be too weak to hold the relay contacts

"open" under the influence of engine vibration when the receiver is used in a model. Too close a differential, on the other hand, may mean such a critical adjustment that the relay again is susceptible to vibration.

The greater the current change, quite obviously, the greater margin available both as regards relay adjustment and its ability to hold in, or stay dropped out under spring pressure when affected by vibration. This can be given by following the detector stage of the receiver with one or more stages of amplification, readily possible with transistors. Thus, with amplification, a current change of 10–20 milliamps is commonplace.

Carried one stage further, the current change which is the characteristic response of the receiver can be amplified to such a degree that it is large enough to operate an actuator direct (see Fig. 4.4). This has the particular advantage of dispensing

FIG. 4.4


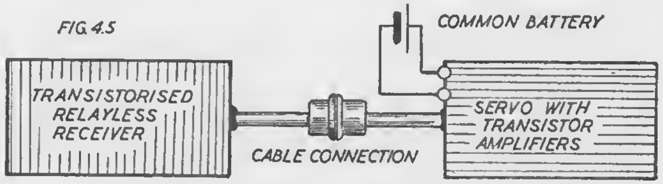
with the relay entirely—resulting in the so-called relayless receiver—and with it the dependency on relay contacts and relay adjustment. In such cases the final stage of the receiver consists of a transistor switching circuit taking the place of the relay and switching a high enough current to operate the actuator direct "on" and "off" in response to the transmitter signal. This is applicable both to "carrier" and "tone" receivers, single-channel or multi-channel.

The value of the current available for switching is finally determined by the electrical load on the switching circuit (i.e. the actuator resistance). Thus a "packaged" relayless receiver is specifically designed to operate with a particular type of actuator (which may be mounted in the same case as the receiver), or suitable for use with certain actuators only. Usually, too, this actuator requires no separate battery, as in a conventional servo circuit, since it is drawing its current from the receiver battery. This is an advantage in simplicity and

weight saving, but if carried to extremes (e.g. using the smallest sizes of battery for the receiver) can result in short receiver battery life and critical operating voltages. In such cases accumulator type batteries are usually to be preferred to dry cells.

There is another type of relayless receiver which is more or less a conventional receiver up to the relay stage but then omits the relay (or relays in the case of multi-channel receivers). This is intended for use with specific actuators, the necessary transistor amplifier stages and switching being incorporated *in the actuator itself* (Fig. 4.5). The output from the receiver

FIG. 4.5



would not operate an actuator direct (only a matching relay). This is the most convenient way of producing a relayless receiver for multi-channel work. Each channel would otherwise require its own separate transistor amplifier and switching circuit to replace each relay built into the receiver.

A further variation on this scheme is to make the transistor amplifier as a separate unit which connects by plug and cable to the receiver. The actuator is then wired to the amplifier unit. The only real advantage with this system is that in the case of relayless multi-channel equipment the receiver and amplifier can readily be changed from model to model and the permanently installed actuators need not be of the more expensive type incorporating built-in amplifiers.

CHAPTER 5

HOME-BUILT EQUIPMENT

Literally hundreds of circuit designs have been published, covering almost every possible type of radio-control system, not a few which have proved highly unpractical as working circuits. From these have emerged a nucleus of designs which have produced workable, if not outstanding results when built by unskilled modellers (unskilled in the art of electronic assemblies, that is), and very good results in the hands of modellers more competent to deal with the subject. In addition to this, circuit drawings of all the leading commercial equipment have been published, or are fairly readily obtainable. On the face of it, therefore, there would appear ample scope for home-made duplication of the best circuits at considerable saving in cost.

In practice this is not so. There is a vast difference between having a circuit drawing and building a receiver or transmitter to achieve results anything like comparable to "professional" treatment of the design. Thus scope is limited, even with sound, simple circuits which should be suitable for anyone to build, provided they have average skill in handling a soldering iron. The more complex the circuit the greater the chance of something going wrong, and the inability of the constructor to appreciate *what* is wrong. At the other extreme some published circuits are essentially one-off experimental subjects which may do what is claimed for them under test-bench conditions but have very severe practical limitations which make them too critical, or just plain unsuited, for normal model radio-control work.

On the other hand, building one's own transmitter or receiver is an excellent way of learning more about practical radio and the electronic principles involved. Provided one sticks to simple, proven circuits for a start then there is every chance of satisfaction in the results achieved, even if results may not be

up to the best standards realised with commercially built equipment. Recently too, especially with the development of transistorised receivers, many designs have been produced in kit form, employing a printed circuit. Here assembly is mainly a mechanical job of identifying, positioning and soldering components in place, following step-by-step instructions. This method of building is not so valuable in providing a background of radio knowledge, but is generally a more foolproof method than leaving the relative beginner to start from scratch, as it were, with a set of components, a circuit diagram, and instructions for wiring up in the conventional or "old-fashioned" manner. Its main limitation is that unless the kit components are carefully chosen—particularly as regards selection of transistors—results obtained can vary widely.

Kit construction has become even more important since the standard of kits has improved tremendously within the last year or so. By adopting transistorised, printed circuit designs the scope of the designs available has also increased considerably, without the more "advanced" circuits being any harder to assemble. More attention has been given to selecting and providing the best quality components, rather than using any components of suitable nominal value in the interest of price and a low-cost kit. Many modern kits, in fact, of the highest quality cost almost as much to buy as an equivalent *complete* receiver or transmitter. The principal "gain" in this case comes from the satisfaction of having built one's own equipment, rather than having purchased a ready-built outfit.

These comments, of course, apply mainly to the modellers with little or no previous radio experience. Those with a certain amount of radio knowledge and practical experience in assembling circuits will probably find their major interest in building and developing their own sets. The resulting model then becomes the means of using or proving their electronic developments. The model enthusiast, on the other hand, regards the radio side of secondary interest as far as the technical aspect is concerned and thinks more in mechanical terms. Thus mechanical assembly of circuits is more in his line.

Since the experienced "radio" man will need little information other than circuit designs (such as those included in this book and the hundreds of others published elsewhere), des-

criptions of "construction" are confined to the modeller's level. Treatment of circuit-design theory and similar aspects of radio control are too technical and too specialised to have a general appeal, especially as by far the majority of successful radio-control work is done with commercial equipment.

As an initial project for home construction the simple carrier-wave single-channel transmitter and matching receiver is probably the best subject. Circuit design can be kept very simple in both cases and even if a typical receiver design is "old-fashioned" by present standards it readily lends itself to following with transistor amplifier stages in place of the relay to give a "relayless" receiver. Several such designs are produced in kit form, some based on a printed circuit further to simplify assembly and eliminate wiring errors.

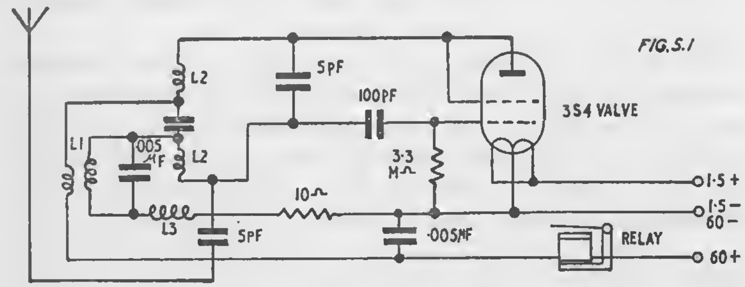
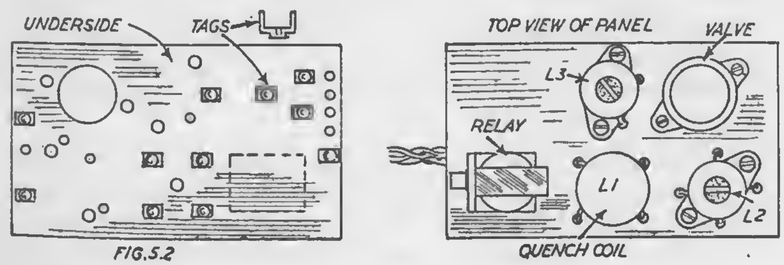


Fig. 5.1 shows the circuit of the Ivy-AM single-channel CW receiver, a popular design developed specially for novices, and Fig. 5.2 the suggested component layout on a Paxolin, Bakelite or Formica panel (the former usually being the preferred material for all model radio-control units, except that glass-fibre panels are often employed with printed circuits).



This circuit is a good exercise in practical radio construction since it involves winding three coils. If preferred, however, these components can be purchased ready wound. That, too, is usually one of the advantages offered by a good kit. Coils are ready wound and other of the more difficult jobs, like drilling the chassis panel, already done.

Coils are normally designed to be wound on standard commercial formers. A former can be fabricated from almost any insulating material—e.g. even plywood (ends) and balsa or dowel (core)—but this is not good practice. Commercial formers are usually made in polystyrene or Bakelite. Of these polystyrene is the preferred choice. Coils which have dust-iron cores threaded into them for tuning purposes *must* be wound on commercial formers since these provide the necessary threaded "bore" to accommodate the dust core or tuning slug.

Winding of the tuning coils and sensitivity coil represents no particular problem. Each consists of a specified number of turns in a single layer on the appropriate former (9 turns each in this case for the tuning coils, and 10 turns for the sensitivity coil), in a specified wire size (28-gauge enamelled wire). It will be appreciated that the electrical characteristics of the coil (principally the inductance) will be strictly dependent on the specification—diameter, number of turns and wire size. Any departure from specification will result in component values different from those to which the circuit was designed and require change of other component values to compensate.

The quench coil represents a rather different problem. Its purpose in the circuit is to "cycle" the receiver in and out of oscillation rapidly to improve sensitivity, and its construction and specification is somewhat critical as a result.

The only difficult part in assembly for a beginner once all components are available and the chassis drilled and fitted with tags, as required, is soldering. This, basically, is a matter of using the right type of iron and flux, and acquiring the necessary technique by practice.

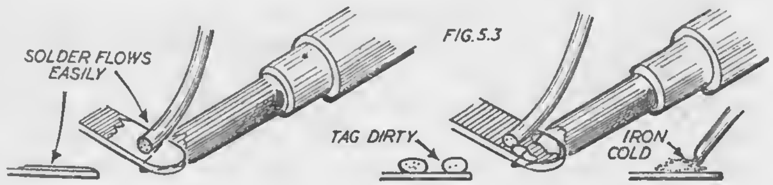
It is imperative to use an electric soldering iron for satisfactory work. The type required is a small iron with a "pencil" bit (i.e. a round bit about $\frac{1}{4}$ inch diameter shaped to a point at the end). Such irons are normally made to work off mains

voltages of 230–250. If they are used on lower mains voltages (e.g. a 200 volt supply) *they will not get hot enough*. In such cases it will be necessary to use an auto-transformer connected to the mains point to boost the supply voltage to the iron to 250.

Cored solder is ideal for electrical work, incorporating as it does its own resin flux. There are actually various compositions of solder each with different melting points. A 60/40 alloy is usually specified for radio wiring, printed-circuit assemblies, etc. No other flux than that contained in the cored solder is necessary, nor should a separate flux be used—e.g. flux should not be applied separately to wire ends, solder tags, etc., to make them "tin" more readily. Acid fluxes (like Baker's fluid), or acid core flux solder, *must never be used for electrical work*. Although they may give a good joint they will produce corrosion and early failure of the wire or component.

The other necessity for good soldering is cleanliness of the wire end, terminals, tags, etc., which are to be joined. Component leads and tags, in particular, get dirty or greasy by handling and require mechanical cleaning until they show a bright metal surface. Other terminal points may get tarnished and similarly require cleaning. Various methods of cleaning are often recommended, from scraping with a knife to cleaning with sandpaper or emery. The latter method is as good as any for general work, provided all dust is blown off the component after cleaning.

To complete a satisfactory joint, both parts to be joined should be tinned. This involves placing the iron against the part to heat it up, then touching with the solder as in Fig. 5.3



when the solder should run smoothly over the surface to wet it. The important thing is that the iron should only be applied for a minimum time—just long enough to heat the end sufficiently for the solder to flow freely. If the iron is held against

the wire end or tag too long excess heat will be conducted to the component itself and may damage it. If the surface does not get sufficiently hot the solder will not melt properly. A hot iron is therefore *essential* for minimum "heating time"; and a clean surface to ensure that the solder, once introduced, can run and "wet" the surface properly.

With both parts to be joined tinned they should be brought together as in Fig. 5.4, the iron applied to heat them up and

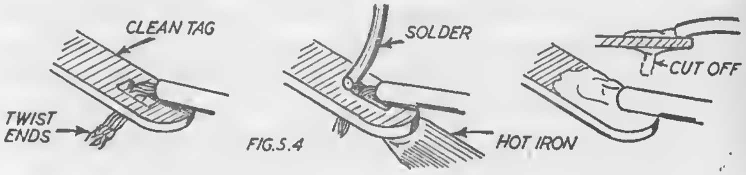


FIG. 5.4

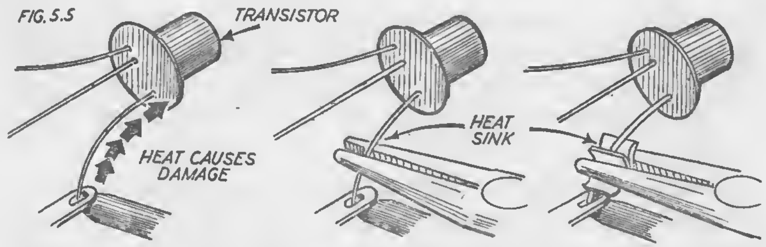
then the joint touched with solder. This should flow evenly and readily, when the iron is immediately removed and the joint held in place until the solder cools—blowing on it if necessary to assist cooling. Again heating should be applied for a minimum time. About two or three seconds should be ample to heat the joint, if the iron is hot enough. Anything longer can cause damage to components through heat being conducted away. If the iron only just melts the solder after this time, almost certainly it is not hot enough. If the solder does not "run" properly after melting, then the joint is dirty. Either can produce "dry" joints or weak connections which in addition to being likely to fail by breaking off may also have high electrical resistance.

Wire leads from components, tags, and so on, may already be tinned and only need cleaning (although a further tinning of *tags* after cleaning is good practice). Wire ends stripped of insulation should be clean and can be tinned straight away. Stranded wire is nearly always used for wiring up and the ends should be twisted together before tinning to ensure that they do not "spread" and leave whiskers of wire sticking out which could short on adjacent connections.

In all cases where there is a chance of a hot iron causing damage to components insulate the component from the heat, e.g. with a piece of moistened "Kleenex" tissue or use some

form of "heat sink" to prevent excess heat being conducted away down the wire. The latter technique applies particularly when soldering transistor leads to the circuit. The transistor is readily damaged by even moderate heat being conducted into it. Gripping the wire being soldered with pliers and a piece of metallic copper, as shown in Fig. 5.5 will ensure that heat is absorbed by the copper rather than conducted up the wire into the transistor itself.

FIG. 5.5



The good soldered joint *looks* right—tidy, neat and well wetted with solder. Its strength can be confirmed by giving a tug with a pair of pliers. A bad joint looks "puddly" and dull. An excess of solder should also be avoided on joints. It does not make a stronger or better joint and may, in fact, be masking a "dry joint" area underneath.

A typical CW transmitter suitable for home construction is shown in Figs. 5.6 and 5.7. The example chosen in this case

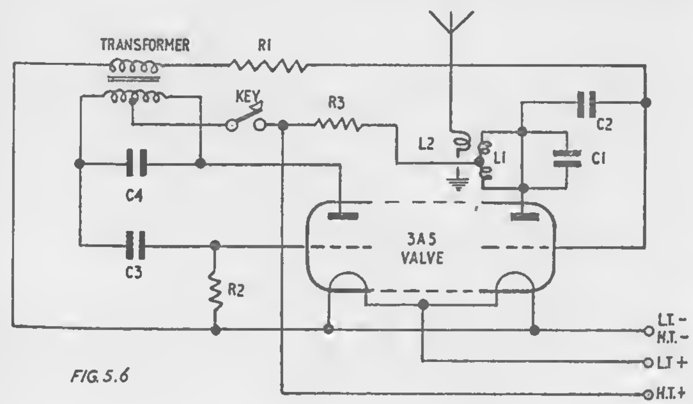


FIG. 5.6

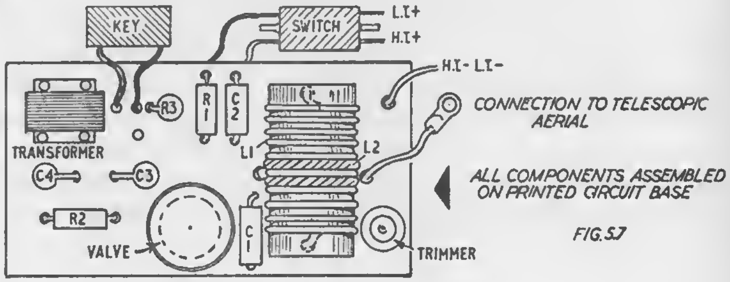


FIG. 5.7

is a typical kit production employing a printed circuit. Other similar designs may utilise a plain Paxolin base plate, drilled and tagged like the receiver described above. Printed circuits can, of course, be home-made although a description of this technique is outside the scope of this present book.

Printed circuit assembly requires a somewhat different technique, with even more emphasis on good-quality soldering. Components are located relative to drilled holes in the chassis, wire leads, etc., bent to conform to these hole positions, the ends pushed through the chassis to locate the component at a suitable height and then fastened permanently by soldering to the printed circuit from the underside.

The printed circuit panel normally requires cleaning before any attempt is made to solder components in place. This is most readily done by rubbing over with fine wire wool until all the copper surfaces are quite bright. Metal polish or similar cleaners should *not* be used.

Since the printed circuit will be laid out to accommodate the components in their correct physical position assembly and fixing of each component, in turn, should be straightforward. With a crowded circuit, however, it is possible to pick up a wrong hole, so positioning should be double-checked against the component layout drawing before finally making the soldered joint. The method of bending wire leads is best described pictorially, the recommendations shown in Fig. 5.8 being representative of good practice.

Note particularly, too, the difference between a good and bad soldered joint on the printed circuit. The solder should flow into a concave fillet, blending into the wire. A "blob" with the wire emerging from the centre like the stem of an

apple is a bad joint—and quite likely a dry joint. The other thing to avoid is too much solder on individual joints. If individual printed circuits are closely spaced or crowded (as they usually are on some part of the circuit, at least) this could cause shorting between the two circuits. Whiskers of solder can also cause similar trouble.

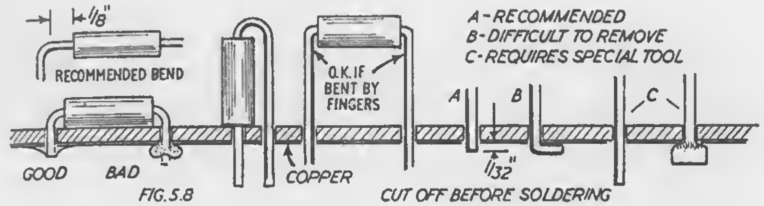


FIG. 5.8

Having mastered assembly techniques with simple circuits the field is virtually wide open to build more elaborate receivers and transmitters from kits. The one type which is not suited to amateur production, however, is the superhet. This represents particular problems in alignment which can be dealt with *only* using special apparatus and a good knowledge of superhet. working principles. One of the most suitable ways of tuning a superhet. receiver for such a critical application as a model radio-control link, for example, is with an oscilloscope.

CHAPTER 6

ACTUATORS

An actuator is a device for converting the switching action of the receiver relay into mechanical movement to operate a control service. In the case of a "relayless" receiver it serves an identical function except that the switching action is provided by the last stage of the receiver circuit and not through mechanical contacts. Actuators themselves are invariably electro-mechanical devices incorporated in a servo circuit separate from the receiver circuit. Where the servo-circuit switching is controlled by a receiver relay, the circuit incorporates its own (separate) battery. With a "relayless" receiver the *receiver* current can be used to operate the actuator direct and so the actuator worked off the same battery as the receiver.

Actuators can be classified as *escapements* or *servos*. An escapement embodies a mechanical "tripping" mechanism which is "held" or "released" by movement of an armature mounted over an electromagnetic coil—basically the same as a relay in operating principle. External power is required to provide movement of the escapement and make this "powered movement" available to operate a control service via suitable mechanical linkage. The most common source of external power for an escapement is a rubber motor, although some escapements embody a clockwork motor. A servo, on the other hand, is basically an electric motor adapted by means of special switching to provide the required movement and mechanical power take-off corresponding to a specific switching-on signal or sequence.

Escapements are designed specifically for operation by a single-control signal—i.e. single-channel radio or one channel only of multi-channel equipment. Servos may be designed for single-channel operation (single-channel servos); or specifically for use with two channels (i.e. two independent signal channels,

one of which switches the servo one way, and the other the opposite way). The latter type are generally known as "multi" servos. There is also a further special class of servos designed to give "proportional" movement when matched to special transmitter signal systems. These are normally specific to a particular system. Escapements and single-channel servos, on the other hand, are applicable to all single-channel use; and multi-servos to all multi-channel equipment.

The action of a simple escapement is shown in Fig. 6.1. In the normal or "neutral" position with the servo circuit "open," the armature locks the rotor against movement by means of toothed end 1 engaging with detent *A* on the armature. If the

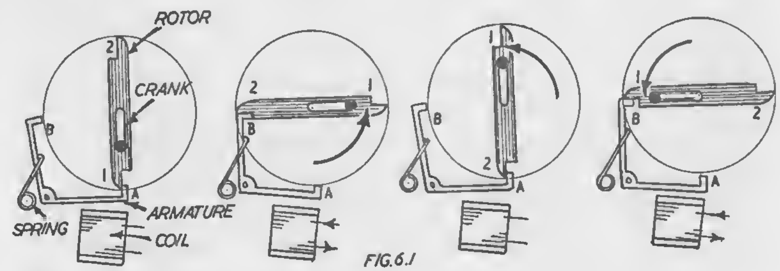
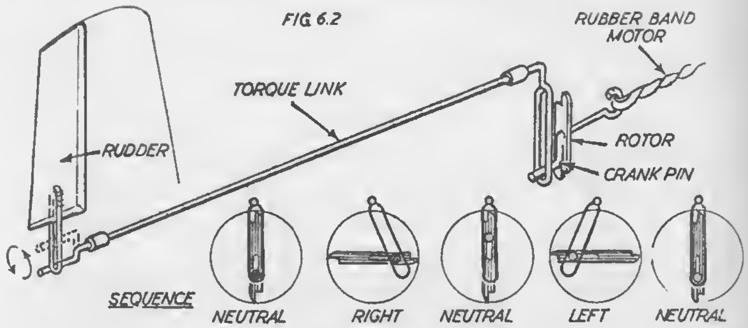


FIG.6.1

servo circuit is now "closed" by operation of the receiver relay the escapement coil is energised, drawing the armature in. This releases the rotor and allows it to rotate through one quarter of a turn until it is brought to rest by tooth 2 striking detent *B*. As long as the control signal is held on (i.e. the servo circuit remains closed) the escapement remains held in this position. On release of signal, opening the servo circuit again and de-energising the coil, the armature drops out to release the rotor which completes a further quarter-turn until stopped by pin 2 striking detent *A*.

The next signal closing the servo circuit produces a further quarter-turn rotation (which position can be held as long as the signal is held on). Release of this signal produces a final quarter-turn rotation to bring the escapement rotor back to its original position.

This controlled movement, one quarter of a turn at a time, can be used to operate a control in similar sequence, as shown in Fig. 6.2 operating a rudder. In the normal position the rudder



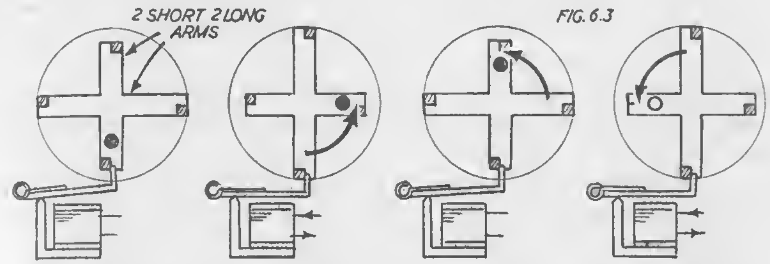
is central. The first signal "held" on right-rudder position. Release of this signal allows the rudder to return to central position. The next signal holds left-rudder. Release of signal returns the rudder to its central position again. The action is *self-neutralising*, since the control surface always returns to its central or "neutral" position on release of signal; and also switches two control positions (right or left) in *sequence*.

This provides a simple and perfectly practical system of control. It is only necessary to remember which control position was signalled last in order to "select" either control position at will. If "right rudder" was the last signal, then the next will give "left rudder." Suppose, however, "right rudder" was required again. This would call for sending one signal, holding momentarily, then releasing and holding the *next* signal. In terms of signalling action of the transmitter button or key this would mean—press, release, press and hold.

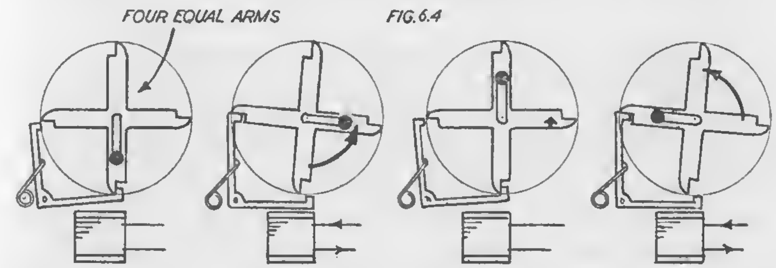
If the sequence is lost, then it is only necessary to hold a signal long enough to observe the response of the model, then release. It is then known that the *next* signal will give the opposite control movement and complete control can be resumed. It needs a little practice to become familiar with "sequence switching" technique, but it is readily mastered.

Simple self-neutralising (S-N) escapements of this type can be made very light and compact and are usually powered by a motor consisting of two strands (one loop) of $\frac{1}{8}$ inch, $\frac{3}{16}$ inch or $\frac{1}{4}$ inch strip rubber. Coil resistance is normally of the order of 8 ohms, to work off 1·5, 3 or 4·5 volts, according to the design. They do, however, have to be precision made, particularly as regards rotor tooth and detent form and alignment, to give

consistent performance. A *good* escapement is very reliable—a poor escapement a continual source of trouble due to its tendency to "skip" or "stick" on the positions where it should normally be held.



Most modern escapements of this type utilise a four-arm rotor when only one detent is called for on the armature. The action is exactly the same, with four quarter-turn movements per cycle of operation (see Fig. 6.3). A four-arm rotor used with a two-detent escapement can give *progressive* quarter-turn movements (Fig. 6.4). In this case application of signal releases one arm from detent *B* and stops the opposite arm on detent *A*.

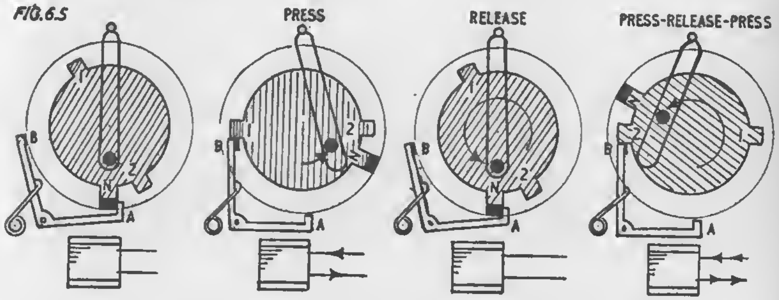


In this period the arm has rotated *nearly* one quarter of a turn. Release of signal allows the armature to drop out. Detent *A* thus releases the arm it is holding, but at the same time detent *B* has now moved in to trap the arm approaching it. This is accomplished within a very small movement—*completion* of a quarter of a revolution, in fact. Thus each signal "on" and release trips the rotor one-quarter of a turn progressively. The signal does not have to be held "on" to hold the quarter-turn position. Hence this type of escapement is excellent as a

secondary actuator for motor speed control in giving three positions which can be selected by a "quick blip" signal (four actual positions, but as far as translation into mechanical motion is involved, two of these are duplicate).

The *compound* escapement is a development of the simple S-N escapement which provides *selective* switching positions. It is somewhat bulkier and heavier—and more expensive—but provides considerably more scope. Instead of a two- or four-arm rotor a toothed or pegged wheel is employed. The *rotational speed* of the wheel is also controlled, usually by a form of ratchet brake to make it practical to select the required control or "stop" positions.

FIG. 6.5



A typical compound escapement action is shown in Fig. 6.5. Neutral position is always held by one special tooth when the armature is not pulled in. This tooth is larger than the others; all the other teeth clear the armature in the "armature out" position. Thus regardless of what control position is subsequently signalled and held, release of signal causing the armature to drop out will always return the escapement to its neutral position. This provides the self-neutralising action.

Signalling is then as follows. Pressing and holding the transmitter button will cause the escapement armature to pull in, releasing tooth *N* (the neutral tooth) and allowing the wheel to rotate until tooth 1 strikes detent *B*. The wheel is then held in this position as long as the signal is held on. Release of signal will release tooth 1 from detent *B* and allow the wheel to rotate the remaining part of one complete revolution until tooth *N* is stopped by detent *A* (neutral position of the escapement).

Suppose, now, a signal press, release, press and hold is given. The first "press" draws the armature in, releasing the *N* tooth and allowing the wheel to start rotating. Immediate release of signal then allows the armature to drop out so that by the time tooth 1 reaches detent *B* position the detent has been withdrawn, allowing the wheel to continue rotation. The next "press and hold" signal then pulls the armature in once more and holds it, with detent *B* now in a position to stop tooth 2. This corresponds to stopping the wheel in the opposite control position.

Thus *either* control position is selectable at will. Press and hold gives right rudder. Press, release, press and hold gives left rudder.[1] There is no need to remember sequence, or which signal was given last. The first form of signal *always* gives right rudder; the second form of signal *always* gives left rudder. Release of signal *always* returns the escapement wheel to the neutral position. The idea of braking the wheel, as mentioned above, is to give a speed of rotation consistent with easy signal "timing." It takes only a minute or two of practice to establish the correct "press, release, press and hold" timing to signal the second control position with absolute certainty.

The compound escapement can also provide a further control position (and most commercial units are, in fact, so made). If a third tooth is fitted to the wheel between tooth 1 and *N* it can be so positioned that stopping the wheel on this tooth corresponds to so near neutral that the main control linkage is "neutral" to all intents and purposes (see Fig. 6.6). This position is selected by signalling—press, release, press, release, press and hold.

This third control position cannot be used directly to provide mechanical movement (although it can be used to give a "kick" action—see Chapter 7). It can, however, correspond to a cam position on the wheel closing a pair of electrical contacts, as shown in the diagram. Thus this third position can be used to select and close an *additional* servo circuit, utilising *another* actuator providing an additional control service.

[1] Whether "right" or "left" rudder is selected by the first "hold" position depends, of course, on the connection of the linkage to the rudder. This description follows the usual convention, however, in that the first selective signal (press and hold) is arranged to give "right" rudder movement.

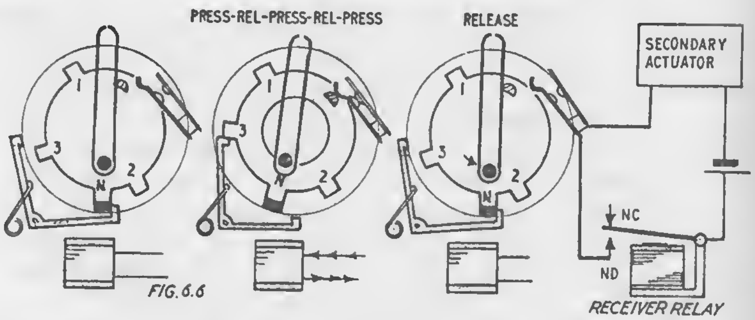


FIG. 6.6

The wiring of this additional servo circuit is important. If wired up directly as an independent circuit to the auxiliary contacts (operated by the third control position), the cam will momentarily close this circuit on *every* circuit of the wheel. This would trip an escapement used in the circuit and be quite unusable as a consequence. If, however, the additional servo circuit is connected through the *receiver relay contacts* as shown in Fig. 6.6 (right-hand diagram) the circuit will only be complete when the receiver relay is in a "signal held" position. In the other two control positions (wheel stopped on tooth 1 or 2), the auxiliary contacts will remain open and so now the only position where the additional servo circuit is completely made is when the third control position is held.

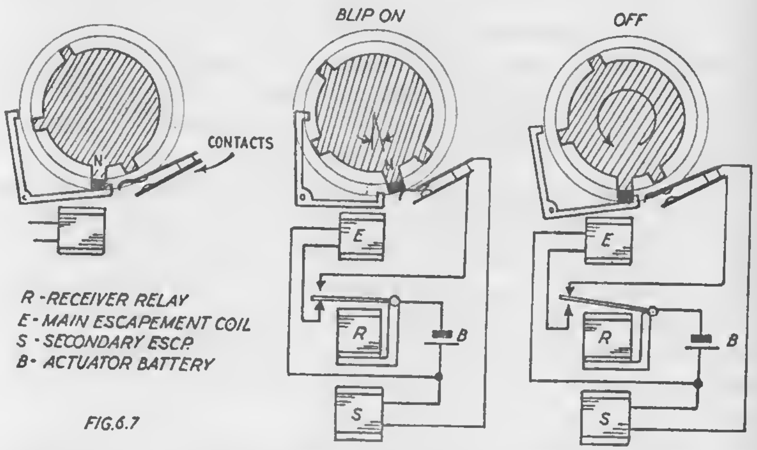


FIG. 6.7

About the only limitation of this third position as a selective control is that it takes a relatively lengthy signalling action to

select—press, release, press, release, press and hold. A very much quicker third control selection can be given by arranging the cam operating the auxiliary contacts in a different position, as shown in Fig. 6.7. Here the contacts are shown operated by the N tooth of the wheel very shortly after it leaves its neutral position. They could equally well be located elsewhere and operated by a cam on the wheel to give the same timing. The main feature is that the contacts are momentarily closed *every time* a control position is signalled, and over the first part of the wheel movement.

To avoid the additional servo circuit connected to these contacts being triggered on *every* signal it is wired through the back or normally unused contact of the receiver relay, as shown. Thus the additional servo circuit is only completed when the auxiliary contacts are closed at the same time as the receiver relay is *not* responding to signal. This corresponds to a quick blip on the signalling button which releases the wheel and allows it to rotate (to complete one full revolution and return to neutral); but by the time the tooth or cam has reached the auxiliary contacts and closed them the receiver armature has changed over to the normally open position so that the additional servo circuit is momentarily complete (for the closing time of the auxiliary contacts). If any other control position is signalled the first "press" holds the receiver relay *in* whilst the auxiliary contacts are momentarily made, and thus maintains the additional servo circuit *open*.

This type of auxiliary contact switching is usually referred to as "quick blip" because of the signal action required—a momentary signal much quicker than the normal "press" followed by "release" to switch to the normal second control position. Unlike "third position" switching it cannot be *held*—hence it is only suitable for "triggering" an escapement in the additional servo circuit. It has the advantage of very rapid selection—just a quick blip on the transmitter button—and the "triggering" action is well suited to operating a motor control through an escapement. The normal "third position" switching can, of course, be held, and is thus suitable for operating either an escapement or a servo and can give rather more scope (see Chapters 7 and 12). Some compound escapements incorporate both "quick blip" and "third position"

switching contacts and thus offer two, selective, additional services (via separate actuator circuits).

Servos, based around electric motors, do not lend themselves to general description since the type of response is almost infinitely variable by incorporating mechanical movements and electrical switching controlling the behaviour of the motor relative to simple or sequence signalling. They can, however, be grouped as single-channel or multi-channel servos, and special servos.

A single-channel servo can produce one, or a variety of movements, according to its specific design and purpose (see Fig. 6.8). It may also be self-neutralising, or not. For the

FIG. 6.8

SIGNAL	PRESS	RELEASE	PRESS	RELEASE	PRESS	RELEASE
SIMPLE	1	2	3	4	1	2
SIMPLE S-N	1	N	2	N	1	N
SEQUENCE SWITCHER	1	1 OR 2	2 OR 3	SEQUENCE DEPENDS ON SWITCH CONTROL		
COMPOUND S-N	1 SELECTED	N	2 SELECTED	N	3 SELECTED	N
QUICK BLIP SWITCHING MAY BE INCORPORATED ON COMPOUND TYPES						

purpose of selecting a suitable type for a particular application it is best to classify them on the same lines as escapements.

A *simple* single-channel servo will provide nominal "left" and "right" control positions, in sequence. "Left" and "right" are nominal as descriptions since the mechanical movement made available may be movement of a crank (like an escapement) or a bellcrank, or a push-pull action of a rod or arm. The control positions may correspond to "left" and "right" rudder, but equally well "up" and "down" elevator, "high" and "low" motor speeds, etc., depending on the control service to which the servo is applied.

Again depending on the design, the control position may have to be held (by holding transmitter signal on), or merely

triggered by a control "blip." The servo motor may "hold" a control position by being held stalled (bad for the motor and giving a high drain on the servo batteries); by slipping against a clutch; or even switch itself off in the control position. In the latter case special switching contacts are necessary to ensure that it will re-start and move to the opposite control position on receipt of the next signal.

The *simple single-channel S-N servo* will provide the same control action, in sequence, but require each control signal to be "held" and return to neutral on release of signal. It thus gives a response just like a simple S-N escapement, and like an escapement continues to draw current all the time a control position is held.

The *compound single-channel servo* provides selective control positions, like a compound escapement, signalled in a similar manner. It may also incorporate additional switching contacts for auxiliary services, these again being selected by sequence switching. Servo types and possibilities in this direction are too numerous to attempt to classify and describe. Without a complete evaluation of the servo under proper working conditions, too, it is impossible to assess the merits and reliability of a particular unit.

Quite a number of compound servos depend for their self-switching action on wipers in contact with a printed circuit disc or panel. In many cases alternative discs are available, each one giving a different servo action. Thus one basic servo may be used as a simple, simple S-N, or for a selection of compound actions, depending on which switching disc is fitted. This is a particular advantage in adapting a particular servo, known to be reliable, for a specific duty. In other cases the same basic servo may be produced in a variety of different models, each with a specific action.

The conventional multi-servo, by comparison, is relatively straightforward, although the gearing and printed circuit switching normally incorporated in its construction may be quite advanced. It requires two separate control channels for operation, and thus is connected to and switched by two relays (see Fig. 6.9). Closure of one relay circuit causes the servo to drive in one direction. Closure of the other relay circuit causes it to drive in the other direction. The action may be self-

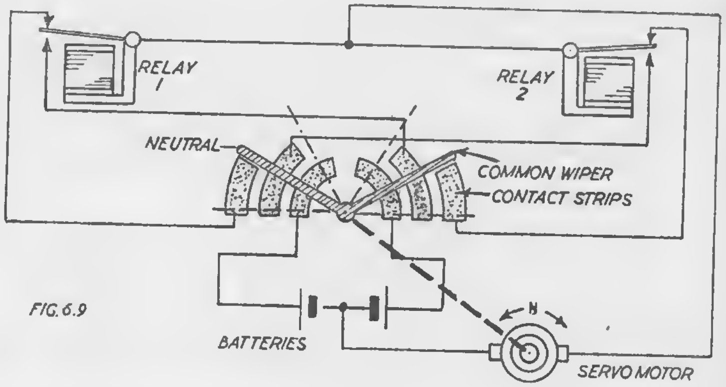


FIG. 6.9

neutralising (returning to neutral on release of signal), or progressive, i.e. inched one way or the other, up to its limit of movement, according to the direction and duration of signal (see Figs. 10.1 and 10.2). The former action would normally be used for main control surfaces—e.g. rudder, elevators and aileron on aircraft models. Progressive action is to be preferred for motor speed controls or trim controls since it enables intermediate control positions to be held without holding on a signal.

CHAPTER 7

SINGLE-CHANNEL CONTROL SYSTEMS

In this chapter we will concern ourselves with the scope of single-channel *systems* as applied particularly to model aircraft and boats. Specific information on suitable model types, installation, details, etc., are covered in subsequent chapters, viz.—Chapters 12 and 13, Aircraft Systems; Chapter 14, Boat Systems; Chapter 15, Land Vehicles.

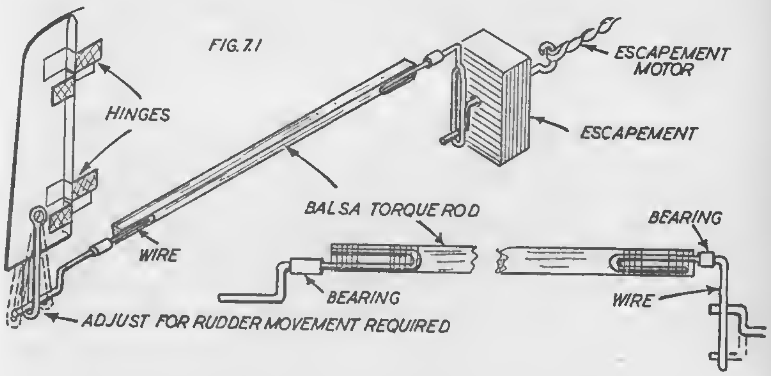
The rudder is the primary control required for the successful operation of a model R/C boat or aircraft, and the one control that cannot be dispensed with however complicated the control system. The simplest form of single-channel radio is well suited to rudder control action, using a simple actuator. A compound actuator, however, offers a distinct advantage in providing selective control positions—right or left rudder at will—plus the possibility of adding further control services.

In the case of model aircraft it can be stated as an absolute rule that *a self-neutralising actuator is essential for rudder control.* With a "progressive" or similar type of non-neutralising actuator the actual position of the rudder can only be judged by the response or behaviour of the model. The effect of rudder movement is powerful, and critical, and it is impossible, in practice, to maintain control without positive rudder positions which can be held at will and the safety feature of being able to revert to neutral rudder position merely by release of control signal.

With a power-boat the position is rather different. A self-neutralising actuator controlling the rudder is usually an advantage, but not necessarily essential. There is more time to judge control response and far less chance of serious damage resulting from loss of directional control. With a fast boat, however, a self-neutralising actuator *should* be regarded as essential as a safety measure.

For single-channel operation an escapement is normally to be preferred to a motorised servo for aircraft. This is because its response time is more rapid. Some servos may be fast enough but the majority are definitely too slow, and the time delay can be disastrous where rapid control response is required. The power available from an escapement driven by a rubber motor is also quite adequate to move the rudder and hold it in position against aerodynamic loads, even on quite large models.

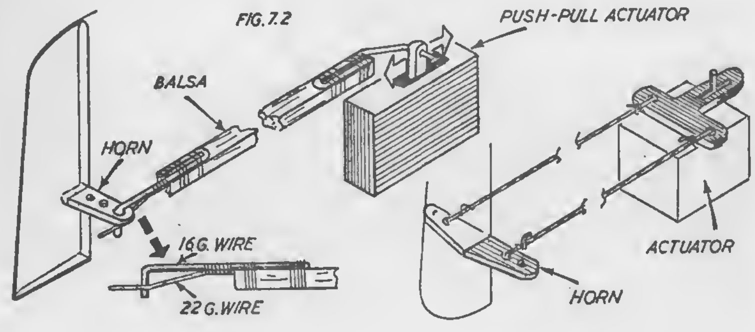
With boats, the power available from an escapement may be suitable for rudder operation on the smaller, low-speed craft; but it is not powerful enough for positive rudder movement on high-speed craft or larger models. A motorised servo is the only satisfactory form of actuator in such cases. It is also usually more convenient to use servos in boats, where bulk and weight problems do not normally arise, in order to dispense with the rubber motor associated with an escapement. A clockwork escapement is an alternative, but this form of escapement would never be used for a primary control on any model.



An aircraft rudder control operated by a simple S-N escapement is shown in Fig. 7.1. The usual escapement motion available is either a crank movement (translated into rotary movement by intermediate linkage), or direct rotary movement of the "power" spindle. This is connected to the rudder-moving linkage by means of a light, rigid torque rod—usually square-section balsa strip with thin wire end fittings bound and cemented in place. The degree of rudder movement obtained

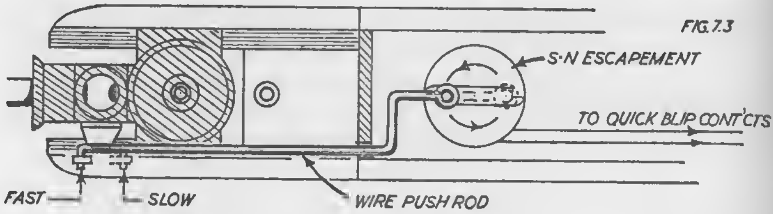
depends on the geometry of the final linkage, the amount of rotary movement being restricted to quarter-revolution steps.

Some actuators may be designed to provide a "push-pull" action (see Fig. 7.2) and must be connected via a rigid arm



to a rudder horn. Alternatively, if the escapement incorporates a rudder bar or rocking bellcrank, a double horn may be used on the rudder and connected to the escapement bar by thread or very thin wire. It will be appreciated that a similar "push-pull" movement can be given by mounting the first type of escapement in a vertical position. This, however, severely restricts the length of rubber motor which can be accommodated and such an arrangement would never be used for an aircraft rudder-control system. It may, however, provide a suitable system for using this type of escapement as a secondary actuator for motor speed control, where a "push-pull" movement is required. The relatively small number of operations obtainable on one winding of the short motor would then normally be sufficient for a single flight.

Motor control can readily be added to rudder control, with single-channel operation, by using a compound escapement. For preference, a compound escapement with "quick blip" switching would be employed, enabling instantaneous change-over of engine speed to be signalled at will. Fig. 7.3 shows the use of a simple S-N escapement as the secondary actuator operated off "quick blip," connected to the throttle lever on the engine by direct linkage.



Note particularly the operation of this secondary control movement. The escapement is positioned so that one neutral position corresponds to "fast" throttle lever position; and the other neutral position to "slow" throttle lever position. The triggering action of the "quick blip" switching then gives a change-over action—from "fast" to "slow," next signal from "slow" to "fast," and so on. This is a perfectly satisfactory system of control since the two extremes of speed are the ones most usually called for.

If, however, the motor control escapement is operated off the "third position" contacts of a compound escapement, an intermediate throttle setting is provided. Selecting the third position and then releasing causes a changeover in throttle position as before. Holding the third position on, however, holds the throttle linkage in an intermediate position, giving an intermediate speed (see Fig. 7.4). This can offer some

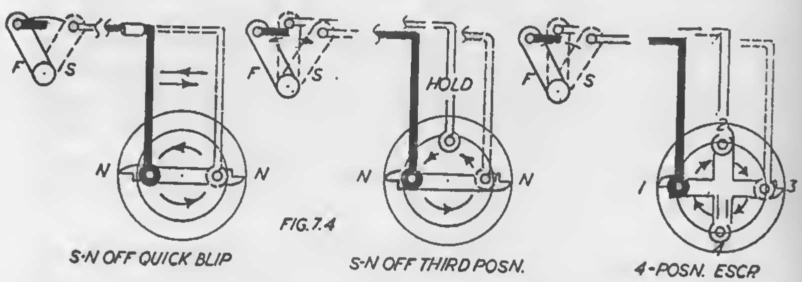


FIG. 7.4

advantages, although when the intermediate throttle position is being held no other control signals can be utilised since the only available signalling channel is being held by this position of the escapement. Intermediate throttle position is best provided by a *4-position* non-self-neutralising escapement operated off "quick blip" (see page 49).

It is not necessary to use an escapement for the secondary (motor speed) control working off the "third position" on a compound escapement. A simple single-channel servo could also be used, or a sequencing servo which stepped through several intermediate positions. Using a servo instead of an escapement generally makes for easier installation and avoids having two escapement motors to wind. For model boat use it would certainly be preferred to an escapement.

With a compound escapement (or servo) which selects control positions it is desirable to arrange the primary (rudder) control to be consistent with standard practice. That is, the rudder linkage (where a rudder horn is used), should always give right rudder on the first signal and left rudder on the second (press, release, press and hold) signal. If it gives the reverse action with a push-pull control, then this can be corrected simply by reversing the rudder control horn from one side to the other.

To utilise escapement controls still further, a compound actuator with "quick blip" and "third position" offers one additional service. In this case the motor speed control would be worked off "quick blip" and the third position used for the extra control; or vice versa. The logical choice for the further control (on aircraft) would be elevator. There are three basic ways in which elevator control can be introduced.

The first is to use either "quick blip" or "third position" switching to operate another simple S-N escapement (or servo) in a separate circuit. This would give "up" elevator and "down" elevator in sequence. There is no point in having a "hold" in neutral elevator (since it would not be possible to operate any of the other controls with the intermediate or neutral elevator position held). At the same time there is a definite advantage in having the fastest possible signal response for elevator and so this would be operated off "quick blip," leaving the "third position" for motor control.

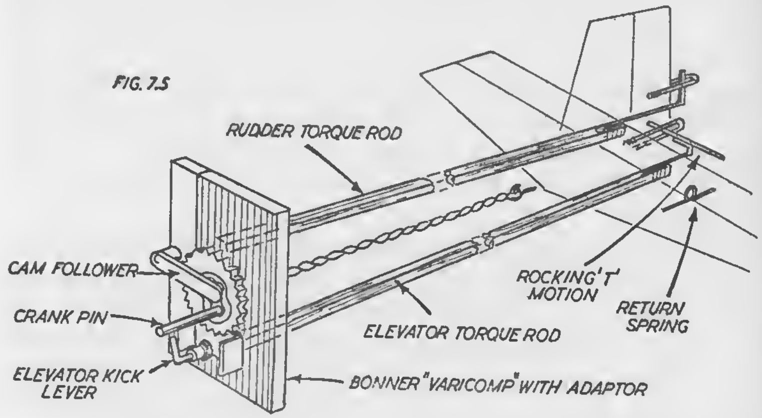
Since the aircraft would have to fly either with "up" elevator *or* "down" elevator, this could only be regarded as a trim control—making, say, "down" elevator the normal neutral elevator position as far as flying trim is concerned and being able to call on "up" elevator for certain manœuvres, e.g. loops. Alternatively the elevator trim could be arranged the

other way—the "up" position corresponding to normal flying trim and "down" available for dives or inverted loops.

In practice this system does not work very well, mainly because the respective elevator positions have to be selected in sequence and if the sequence is "lost" at a critical moment the wrong elevator control may be applied.

The second possibility is to use "kick elevator" movement provided on some compound escapements at the "third position" of the escapement wheel (see Fig. 7.5). When this

FIG. 7.5



position is selected and held a trip on the rudder torque arm or escapement crank provides a rotary movement on a separate spindle. This can be linked to the elevators, as shown, to provide movement in one direction—"up" or "down" as required. The control surface is centred by spring action and so as soon as the signal is released the elevator returns to neutral position.

This method does work quite well in practice, its main limitation being that the elevator is driven by the escapement motor which may not be powerful enough for positive control movement under all flight conditions, especially as it has to act against the elevator centring spring.

The third alternative is to use more than one compound escapement "in cascade." The actual method or cascading depends on the type of compound actuators available, which have to be linked, mechanically and electrically, as a matched

pair. This is done by using wiper circuits on the printed circuit bases of the two units, and also connecting them mechanically so that the wheel of one drives the secondary compound or "cascaded" escapement (see Fig. 7.6).

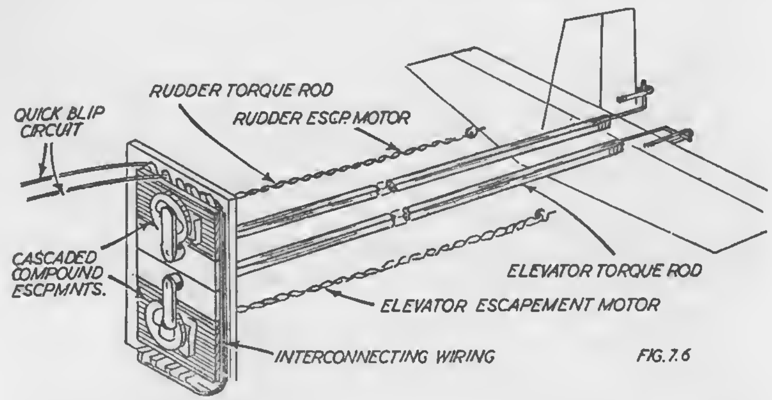


FIG. 7.6

It is then possible to provide four selective signalling positions, e.g.

Press and hold—right rudder.
Press, release, press and hold—left rudder.
Press, release, press, release, press and hold—up elevator.
Press, release, press, release, press, release, press and hold—down elevator.

Release of any control, after holding, automatically returns both escapements to neutral. In addition, "quick blip" switching is also available for operating the separate motor speed control actuator thus giving in effect "five-channel" control response from a single-channel receiver.

Although, on a bench rig at least, a third compound escapement can be cascaded with the first two, or a fourth, fifth, and so on adding even more control services, *two* cascaded escapements represent the absolute practical limit for aircraft work because of the time delay involved in signalling even the "fourth" command. Very much depends on the skill of the operator in handling even twin cascaded units. Although a separate rubber motor is used to power the elevator escapement, rubber power is "marginal" for elevator movement, especially on aerobatic models which may achieve high flight speeds.

An aerodynamically balanced elevator is virtually essential to relieve the escapement motor of excessive load and consistency of performance depends very much on achieving the optimum degree of balance.

Nevertheless, the cascaded escapement system can give excellent results and "multi-channel" scope with simple and relatively inexpensive equipment. It is not as effective as true multi-channel equipment where each control position is selected immediately and positively, because it relies mainly on mechanical movements rather than on direct electronic switching. It is essentially an aircraft system rather than one for boats, vehicles, etc., where sequence-switching servos or servo circuits selected by a sequence switcher are more practical for "multi-control" operation with a single-channel receiver (see also Chapter 14).

For boats, simple rudder control is usually best provided by a simple S-N servo; or where additional duties are called for, such as motor speed control, a single-channel compound servo. The main controls—"right rudder" and "left rudder" should be capable of positive selection. Any number of other secondary controls can then be selected in sequence.

Motor speed control is important on high-speed craft, and so this should be capable of positive selection, which virtually covers all the *functional* needs of a power-boat. In the case of the slower boat, powered by an electric motor, an ability to stop and reverse the motor would be desirable, followed by as many other secondary or novelty services as the builder may desire to incorporate. The fact that the sequence can be lost without hazard to the safety of the craft makes them non-critical controls, whereas virtually *all* controls on a model aircraft are critical. It does not put a slow speed-boat in danger, for example, if loss of sequence lowers a flag instead of switching on the navigation lights. On the other hand "down" elevator applied accidentally to a model aircraft flying near the ground could result in its total destruction.

Where more power than is provided by an escapement is required (and lacking a compound servo with the right action or performance), an escapement may be used to control a typical multi-servo. This is not a usual solution but may have advantages in particular circumstances—e.g. to utilise a multi-

servo of proven reputation and performance with single-channel radio.

In this case the escapement (compound or simple, depending on whether or not additional switching services are required) is used as an electrical switcher, as shown in Fig. 7.7. For

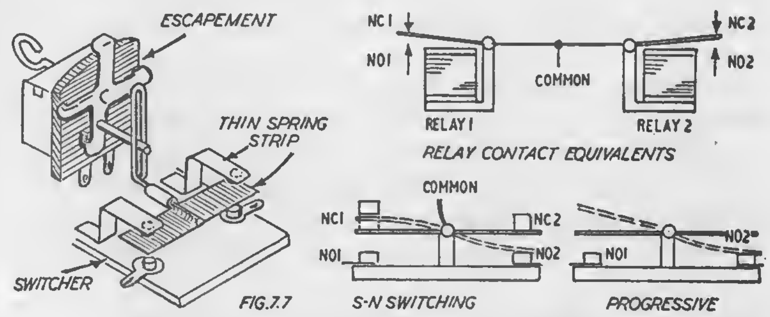


FIG. 7.7

progressive control response from the multi-servo two contacts only are required, one on either side of the leaf spring. This is a method of making progressive throttle control available on a single channel, or progressive steering for a boat rudder or car steering. If two additional contacts are provided the self-centring action of the multi-servo can be utilised. The two sets of contacts involved then correspond to the two sets of relay contacts which would normally be used with multi-channel operation of the servo; and the left spring to the commonly connected armatures of the two relays. The success of such a system depends on the switching set being well made with a light, springy leaf for the contact leaf which makes good contact with the separate contacts without causing the escapement to bind or stick. Also the contacts must be kept clean.

CHAPTER 8

PROPORTIONAL SINGLE-CHANNEL SYSTEMS

THE previous chapter described the extension of functions possible, up to a practical limit, by electro-mechanical "trickery," as it were, external to the actual radio link. In other words, the radio link still provides only a simple "on-off" signal which is made to perform a variety of duties by sequence-switching with respect to allied actuator circuits. The form of control response realised is essentially "on-off"—i.e. a full-control movement to one position, reverting to neutral on release of signal, or "triggering" from one position to another in the case of a non-critical secondary control. The use of progressive or "inched on" control movements is very restricted with single-channel operation, and virtually out of the question for any type of aircraft control.

"On-off" or "bang-bang" control movements, as they are sometimes called, are far from the ideal for smooth response on the part of the model being flown. Rudder control cannot be held on with a model aeroplane, for example, to give a continuous turn. Holding on the rudder control will rapidly put the aircraft into a spiral dive. To produce a reasonably steady turn without excessive loss of height the same rudder control position has to be blipped on and off—just enough to start the model turning, then off again before it begins to roll into a spiral dive, another blip of the same rudder position to keep it from straightening out, and so on. It will be appreciated from this that rapid selection of control positions is essential with "bang-bang" controls and the more complex the system through sequence switching, the greater the possibility of error, and the greater the skill required to maintain full and complete control. Multiple controls, operated through a single-channel system, do not make the model *easier* to fly because they provide more control services. They make it more difficult.

To avoid having to manœuvre the model in "steps," as it were, *proportional* movement of the main controls becomes essential. That is to say the actual control movement selected is variable and corresponds to the *degree* of control selected by movement of a control lever at the transmitter end. In the case of aircraft the rudder and elevators should, essentially, be capable of "proportional" operation for smooth control. In the case of a boat, car, etc., proportional steering would be adequate.

Simple proportional control is something which can be achieved with single-channel equipment, and at no great extra expense or complication. The basis is a means of *pulsing* or interrupting the transmitter signal (Fig. 8.1) either mechanically or electronically, so that the receiver relay response can

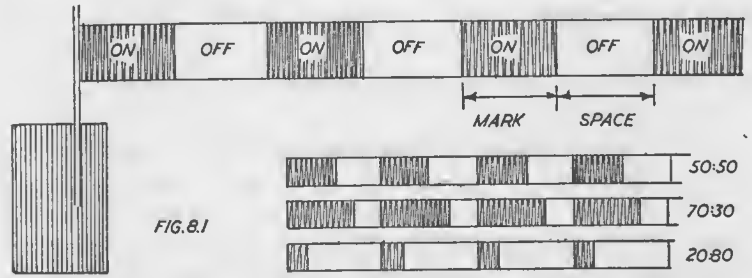


FIG. 8.1

be varied in sympathy with the form of pulsing. This is allied to a special actuator—either one with twin coils or a simple electric motor adapted to respond to "proportional" switching.

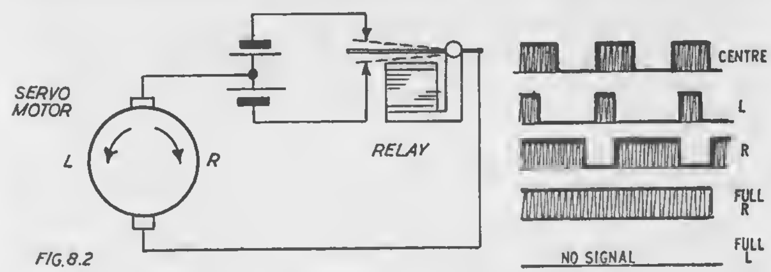


FIG. 8.2

A basic actuator circuit is shown in Fig. 8.2. Two servo batteries are used, connected so that when the relay armature is making on one contact the motor is energised to drive in one

direction and when the armature moves to the other contact the motor drives in the other direction. If the armature was held between the two contacts, touching neither, no current flows to the motor since the motor circuit is broken. To avoid the motor stopping in the last position it was in before the circuit was broken, a spring device is fitted to pull the driving crank on the motor back to a central (neutral) position when the relay armature is in mid-position.

Consider now the receiver responding to a transmitter signal which is "pulsed" on and off. During the "on" period of the signal the relay will pull in, closing the circuit to drive the motor one way. During the "off" period the relay armature will drop out, completing the circuit for the motor to drive the other way. The "on" time of a pulsed signal is usually referred to as "mark" and the "off" time as "space." If the mark : space ratio is 50 : 50 (equal on and off periods) the motor will obviously oscillate about its neutral position. Any control surface driven by the motor will thus oscillate about its neutral position.

If the *rate* of pulsing is now increased, still maintaining a 50 : 50 mark : space ratio, there will come a time when the "on" and "off" switching periods will be so small that the motor, to all intents and purposes, will remain stationary. It will just not have time to move in one direction before the switching of the circuit has changed to energise it in the other direction. A 50 : 50 mark : space signal pulsed at a sufficiently high rate will, therefore, maintain a neutral control position. In practice it is only necessary to increase the pulse rate to such a figure where the oscillation about the neutral position is rapid enough not to have any appreciable effect on the performance of the model—i.e. at least four pulses per second.

Suppose, now, that the mark : space ratio is altered (whilst maintaining the same pulse *rate*). This means that there will be a longer "on" time per pulse than "off," or vice versa, making the relay armature dwell longer on one contact than the other. This will bias the oscillation of the motor in one direction or the other or, in effect, give it a new "neutral" position displaced from the original, true neutral corresponding to the 50 : 50 mark : space ratio signal.

The displacement of this new "neutral" position will be proportional to the change in mark : space ratio, with corresponding movement of the control surface driven by the motor. Thus with the mark : space ratio variable between extreme limits—

- 50 : 50 mark : space ratio corresponds to neutral control position;
- 100 : 0 mark : space ratio corresponds to extreme control position one way;
- 0 : 100 mark : space ratio corresponds to extreme control position the opposite way.

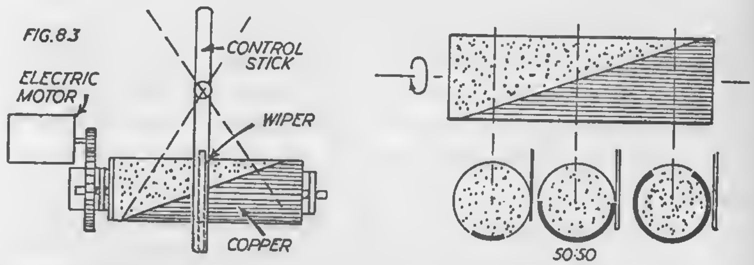
Intermediate values of mark : space ratio between 50 : 50 and 100 : 0 one way produces a *proportional* control movement in that direction; and intermediate values between 50 : 50 and 0 : 100 a *proportional* control movement in the other direction.

The practical limits, of course, are not necessarily 100 : 0 and 0 : 100 but some lower ratio in each case. 100 : 0 mark : space means all "mark" or continuous signal which would hold the relay in and allow the motor to drive continuously one way. Similarly 0 : 100 mark : space would correspond to the motor driving continuously the other way. It would then be necessary to add mechanical stops at each side to limit the full travel of control movement and, preferably, arrange a slipping clutch drive on the motor so that when coming up against a stop the motor can continue to run under a relatively light load instead of being held stalled. The objection to holding a motor stalled is the very high current it draws under this condition. Nevertheless, some pulsed systems do employ mark : space ratio signalling ranging from 100 : 0 to 0 : 100 and mechanical stops with and without a clutch on the motor. This gives positive "full" control positions as well as intermediate "proportional" positions.

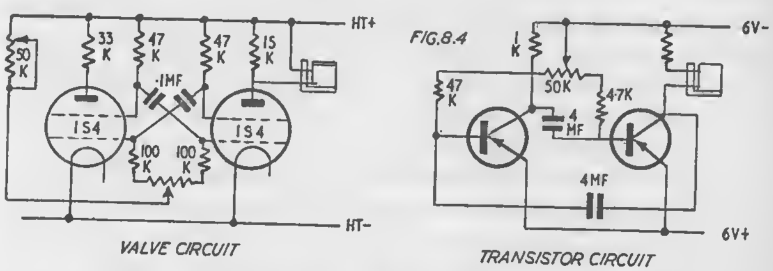
Requirements at the receiver end to work the system are a relay sensitive enough to respond to the pulse rate used and capable of adjustment so that the armature maintains a central (neutral) position with 50 : 50 mark : space ratio. At the transmitter end all that is required is some form of variable switching device which can be used to interrupt the

normally continuous output (CW) signal and "pulse" it at a rate determined by movement of a control stick (as being a logical method of proportional aircraft control) or knob (simulating the wheel of a boat or car). Since the system operates on only one control surface, as applied to single-channel, it must be used for the steering control on any type of model.

The pulsing device can be mechanical, or electronic. A reliable mechanical pulser consists of an insulated drum or roll half covered with copper foil, as shown in Fig. 8.3. This



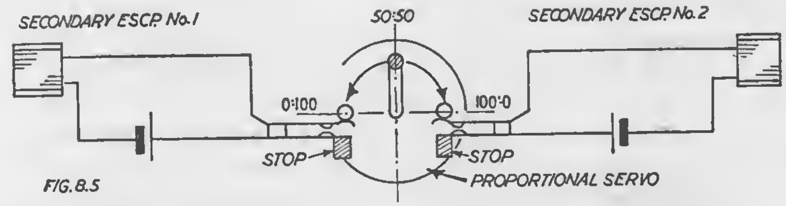
drum is driven by an electric motor, geared to give the required number of revolutions per second (equivalent to the required pulse rate). A pivoted wiper is then arranged to sweep the drum, its position along the length of the drum—determined by the position of the control stick—governing the ratio of contact strip : insulating surface swept in a revolution. By connecting into the transmitter output circuit, as indicated, movement of the control stick provides infinitely variable mark : space ratio in the transmitter signal.



In a typical electronic switching circuit (Fig. 8.4) the mark : space ratio is variable by movement of a potentiometer

with transmitter output switching via a relay. Relatively few pulser units are produced commercially and the majority of those in use in this country, at least, are home-made.

Although the application of single-channel proportional is limited to rudder control two additional "triggering" controls can be provided, utilising the extreme positions (maximum and minimum mark : space ratios) to select these additional services. To achieve this the range of control-stick movement utilised for proportional rudder control is made less than the full range of mark : space ratio available from the pulser. If the control stick is advanced beyond either of these arbitrary limits the extra movement of the motor crank can be utilised to close a pair of contacts and thus trigger an auxiliary circuit (see Fig. 8.5). Only a "triggering" action can be employed



since to hold either extreme control position would also mean holding an extreme rudder position at the same time. There are also other means of providing an auxiliary control service with single-proportional by additions to or modifications of the receiver circuit but these are of a more advanced electronic nature and beyond the scope of this book.

A clever development from simple proportional is simple-simultaneous (Simpl-Simul) or "Galloping Ghost" as it is normally called in this country. This again uses a pulsed transmitter output signal but in addition to varying the mark : space ratio also provides for varying the pulse *rate*. Rudder control is given by the variation in mark : space ratio and elevator control by the variation in pulse rate, with the actual separation of the two signals being done mechanically.

In this system rudder and elevator linkage is as shown in Fig. 8.6. The amount of rudder offset is dependent, as before, on the mark : space ratio causing the motor to oscillate about a

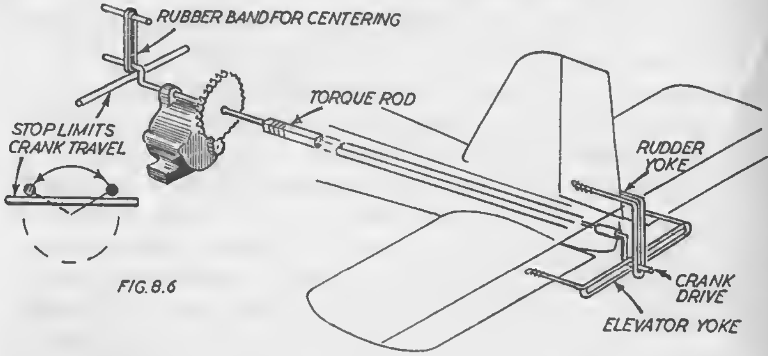


FIG. 8.6

"neutral" appropriate to the particular mark : space ratio being received. Variation in pulse *rate*, however, varies the *amplitude* of the oscillations and this is used to flap the elevators up and down.

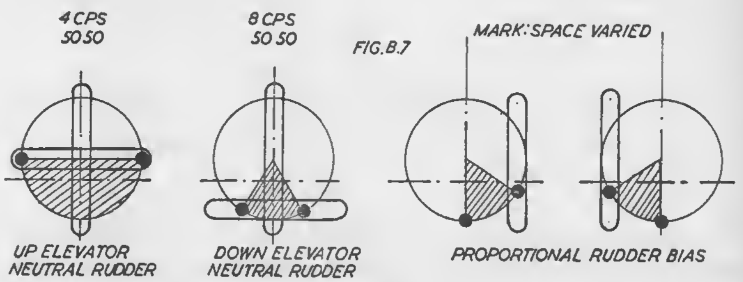


FIG. 8.7

This action can be followed in Fig. 8.7. With 50 : 50 mark : space ratio and a slow pulse rate (4 cycles per second) the amplitude of oscillation will be about a maximum. The rudder will be neutral (50 : 50 mark : space signal) but the bias as far as the elevator linkage is concerned will be "up." Increasing the pulse rate (still holding 50 : 50 mark : space ratio) will reduce the elevator-up bias progressively until at some high rate (e.g. about 8 cycles per second) it will correspond to "down elevator" position. Any intermediate or proportional elevator position between "up" and "down" can thus be selected by varying the pulse rate between 4 cycles per second and 8 cycles per second. At the same time, and independently, any proportional rudder position can be selected by varying the mark : space ratio of the signal.

The pulser, in this instance, utilises two separate mechanical or electronic units—one to vary the mark : space ratio as with simple-proportional, and one to vary the pulse rate. The controls of these two pulsers are most conveniently connected to a common stick so that sideways movement controls the mark : space ratio (rudder control) and fore and aft movement the pulse rate potentiometer control (elevator movement).

In point of fact although offering a proportional control response both rudder and elevator are, of course, oscillating all the time. Provided the minimum pulse rate is high enough (not less than 4 cycles per second) this has no appreciable effect on the flight path. To some extent, too, there will be some interaction between the two separate control actions so that with a deviation of mark : space from a 50 : 50 ratio some elevator "bias" may be apparent, even at a steady pulse rate. It is not necessarily a foolproof system although it is relatively simple, and normally needs a fair amount of practice to operate successfully even if working satisfactorily. It is, however, an attractive solution for "poor man's Multi."

Simple-proportional and simple-simultaneous cover the two main types of "advanced" single-channel systems which have proved practical and workable outside a purely experimental basis. There are many other "advanced single-channel systems," but most are of a "one-off" or purely experimental nature and not suitable in their present form for general use.

None of these systems, incidentally, is *truly* proportional with open-loop servo circuits—that is, the control surface does not necessarily assume an *exact* proportional position, relative to the movement of the transmitter control, under actual working conditions. For more information on this point, see Chapter 11.

CHAPTER 9

MULTI-CHANNEL SYSTEMS

ALL single-channel control systems rely on direct switching (on and off) of the transmitter signal—either the carrier wave in the case of "carrier" transmitter-receiver combinations, or the "tone" or A.F. signal used to modulate the carrier with "tone" equipment. With multi-channel systems, however, more than one tone is produced by the transmitter, to be superimposed on the carrier at will (i.e. by operating the appropriate button or control switch selecting a particular tone). Each "tone" then represents a separate signalling channel which is interpreted or decoded directly by the receiver to close an associated servo circuit.

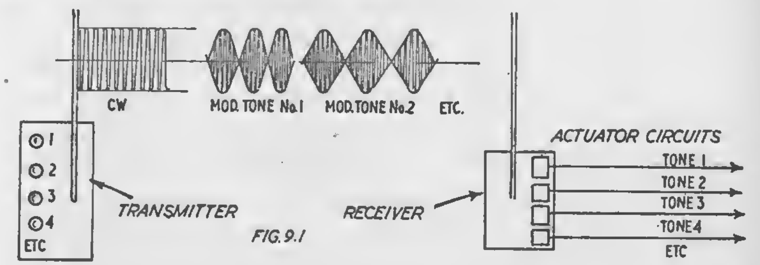


FIG. 9.1

A typical multi-channel system is shown in block diagram form in Fig. 9.1. The number of separate channels or "tones" available from the transmitter is dependent on its design, with eight or ten as the usual maximum. It is possible to cram even more tones into the practical range of A.F. frequencies without their being too close together (which could cause interference between one tone and another and thus affect servo circuits other than the one directly signalled). Ten channels, however, are sufficient to cover all control requirements for the most advanced type of model aircraft. Less channels are required for complete control of a model boat.

Generation of a range of different tones at the transmitter end represents no particular problem. The main thing to ensure is that the circuit design and method of generating the tone frequencies is stable enough so that tone signals cannot drift off frequency and in consequence lose receiver response, or encroach on the frequency of a neighbouring tone circuit and cause false response. The method of decoding the different tones at the receiver end is fixed and the transmitter tones are tuned, initially, to the fixed frequencies to which the receiver responds. The tones are sorted out at the receiver end either by a resonant reed bank (by far the most popular method), or by filter circuit. Each individual reed (or filter) then passes only one fixed tone signal (responding only to a very narrow band of frequency). It needs to be fairly sharply tuned in this respect to avoid responding to adjacent tones. Virtually the whole of the range of audio frequencies used for single-channel "tone" signalling is available for selection of the multi-channel individual tones, but is primarily dependent on the method of decoding. A resonant reed offers the simplest and most direct method of decoding any particular tone but in this case all the separate tones must be accommodated within one octave (e.g. typically between 250 and 470 cycles per second). It is, basically, an electro-mechanical filter with each individual reed "passing" a particular frequency. An electronic filter, comprising a tuned circuit, will do a similar job and can accept tones over a much wider range of frequencies, but as the number of channels increases the number of individual filter circuits required puts up the bulk and weight of the receiver, and its complexity. The necessary number of electro-mechanical reed "filters" can all be mounted as a single unit called a reed bank.

One of the earliest types of multi-channel receivers was designed to respond to two separate tones only and operated on the tuned relay principle. Here the individual relays, of specific resistance, functioned as part of the filter circuit and responded only to one specific tone. Circuits of this type are still in use (and manufactured commercially).

The use of electronic filter circuits for separation of the individual tones is generally to be preferred to "tuned relay" response, where the filter block sorts out the tone necessary to

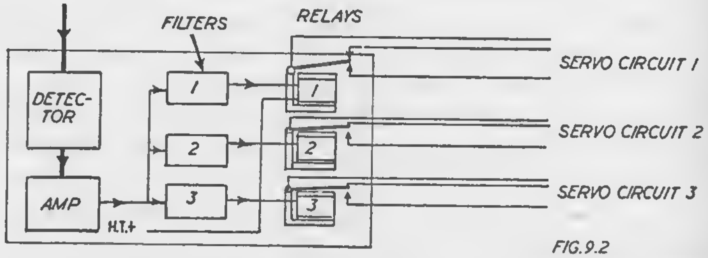


FIG. 9.2

operate a selected relay and associated servo circuit (see Fig. 9.2). This diagram shows a three-channel system, which is a common choice for tuned filter circuits. It will be appreciated that the operation is essentially similar to that of a single-channel tone receiver except that there are three possible "responses" to signal, according to which particular tone is superimposed on the transmitter carrier, each feeding a separate relay and its associated servo circuit.

A little further thought will show that a two-channel or three-channel system is not necessarily restricted to two or three control functions, respectively. Each servo circuit can be compounded, as with single-channel equipment (see Chapter 8), to provide sequence or selective operation of controls via that particular channel. Each channel, in other words, can control a simple or compound actuator in its servo circuit.

To describe a typical example of "compounding" via a two-channel system, each channel controls a compound actuator, one actuator operating rudder and engine speed control (via third position or quick blip position) and the other elevators (with a further control service available via "third position" or "quick blip"). Rudder and elevator controls are thus provided independent of each other, with selective engine speed. Each transmitter tone control switch is then used like a single-channel transmitter switch. Signalling is as follows—

Switching Tone 1

Press and hold—right rudder.
Press, release, press and hold—left rudder.
Rudder reverts to neutral position on release of signal.
"Quick blip" *or* press, release, press, release, press and hold—engine speed changeover.

Switching Tone 2

Press and hold—up elevator.
Press, release, press and hold—down elevator.
Elevator reverts to neutral position on release of signal.
"Quick blip" and/or "third position" signalling available for further service(s).

Depending on the type of circuit and method of filtering it may, or may not, be possible to signal on both tones 1 and 2 simultaneously. The only real advantage of compounding multi-channel receivers however—apart from the obvious one of utilising simpler, less expensive equipment—is independent switching of two main services (e.g. rudder and elevator) and avoiding the complication and delay realised with "cascaded" actuators. In all other respects it suffers from the same limitations as single-channel operation applied to multiple control services—indirect switching via selective sequences.

The real advantage with multi-channel signalling comes with having enough channels available for direct switching of each control position required, via motorised servos. Thus for rudder control two channels are required—one to switch right rudder and one left rudder, self-neutralising on release of signal. The same with elevators and ailerons on aircraft. The availability of two signalling channels to operate any *one* actuator also means that a particular (non-critical) service can be operated *progressively* where this is an advantage (e.g. engine speed control giving a full throttling range; or elevator trim control).

The majority of equipment used for true multi-channel radio-control work is based around the reed receiver—that is, a receiver using a resonant reed bank as the filtering device for separating the various tone signals. A reed bank has the advantage in that for a single component the number of filtered circuits can be increased simply by increasing the number of individual reeds forming the bank without additions to the basic receiver circuit itself. The only complication which then arises is providing a separate relay to be switched by each reed and even this has been overcome by later development of the "relayless" receiver where the reed itself acts as the switch for the servo circuit.

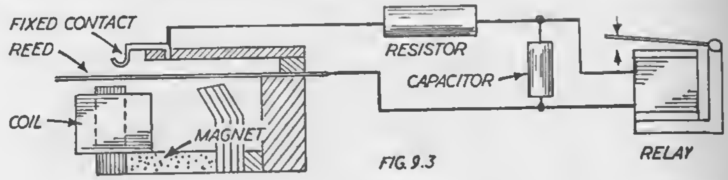


FIG. 9.3

The action of a simple resonant reed is shown in Fig. 9.3. The reed itself consists of a thin strip of springy metal (usually flat, but in some designs it is made of wire), clamped at one end and positioned over a coil. In this respect it is very similar to a normal relay (and in fact is correctly termed a resonant reed relay), except that one end of the reed or "armature" is fixed instead of being pivoted. The other difference is that a permanent magnet is incorporated in the magnetic circuit to give a bias to establish a definite operating point for the reed on the magnetisation curve of the circuit, and also to make the reed polarity sensitive.

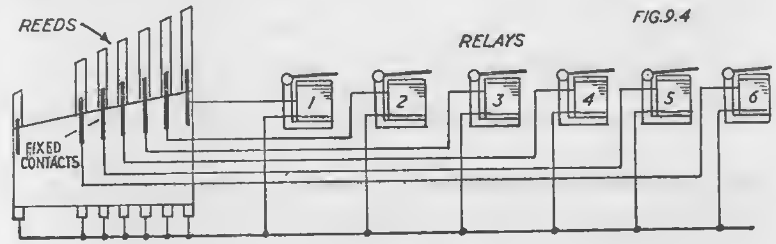
Depending on the length, thickness and width of the reed, and the material from which it is made, it will have a specific resonant frequency. The field coil in the magnetic circuit receives the "tone" signal detected and amplified by the receiver and is thus subject to excitation by alternating current. When the frequency of the exciting current corresponds to the resonant frequency of the reed, the reed will commence to vibrate "in resonance" and continue vibrating as long as that specific frequency of excitation is maintained. Thus the reed responds to a particular tone frequency being received by the receiver.

The vibration of the reed means that during part of its cycle it is "making" against its contact and the relay connected to this contact and the reed itself is effectively switched "on." The actual period of "make" is relatively small—usually only about 1 to 10 per cent of the complete cycle of vibration. The purpose of the capacitor in the circuit (Fig. 9.3) is to act as a sort of "reservoir" when charged up by initial closure of the circuit and help maintain a steady current through the relay coil. Thus the relay in the circuit is held "in" and the relay contacts controlling the servo circuit "made." The purpose of the resistor in this same circuit is merely to limit the initial

or peak current when the circuit is first closed by the reed and so prevent an excessive current being passed through the reed fixed contact and the reed itself.

Many reeds can be mounted in a single magnetic circuit and if each is made a different length, each one will respond to a different frequency of excitation. This is the principle of the reed bank which may mount anything from three to twelve individual reeds, each reed connected to a separate relay which it thus controls. Any particular tone will, therefore, cause its corresponding or "tuned" reed to vibrate and operate that appropriate relay and through the relay contacts, the appropriate servo circuit (see Fig. 9.4). Each servo circuit is thus capable of being switched at will, merely by transmitting the particular tone signal.

FIG. 9.4



Despite the obvious advantage of simplicity a reed bank is a critical component and must be precisely made to work efficiently and consistently. The individual reeds themselves must be securely anchored at one end so as not to dissipate energy (thus losing sensitivity); precisely fixed as regards length (so that they maintain a constant resonant frequency); be a good conductor (since the reed is one of the contacts); and be of a material which has good "spring" characteristics, unaffected by changes of temperature or "fatigue" effects, which could cause the resonant frequency to drift.

The magnetic circuit is important as governing the sensitivity of the reed, efficiency of operation and the contact pressure achieved. Contact positioning is also important. If the (fixed) contact is located near the free end of the reed the duty cycle (or ratio of time "on" to time "off") is very low (of the order of 1 per cent). It is usual, therefore, to position the contact in from the end of the reed to improve the duty cycle to achieve

about 8 per cent closure time. A flexible contact would also improve the duty cycle, but this is not a practical solution since it would lower contact pressure and also tend to drift with time.

Contact position is also closely related to the band width over which the reed responds. An individual reed will not vibrate in resonance at one spot frequency and no other but rather will resonate over a range of frequencies and "peak" at the true resonant frequency (see Fig. 9.5). This diagram is

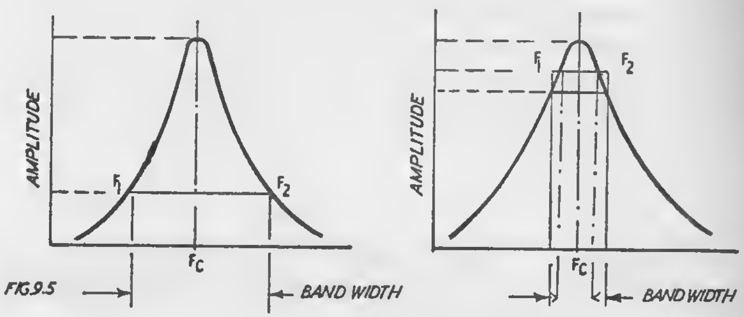


FIG.9.5

typical of reed amplitude in the region of resonant frequency (F_c). The lower the contact position (i.e. the less amplitude of vibration needed to make contact) the greater the band width over which contact is made. Conversely, the higher the contact the more selective the reed circuit becomes. Contact spacing must also satisfy certain physical requirements (to act effectively *as* contacts for the current being carried) and so is not something to adjust at will. The degree of frequency separation (i.e. the effective band width) is thus largely a function of the design of the whole unit and becomes increasingly critical as the number of individual reeds is increased. Each must provide sufficient sensitivity for independent response *within* an octave for if the tone band is spread beyond one octave *two* reeds will resonate at the same (harmonic) frequency. Hence the production of reed banks is normally left to the specialist manufacturer. Few "home-built" units can hope to achieve the degree of performance required.

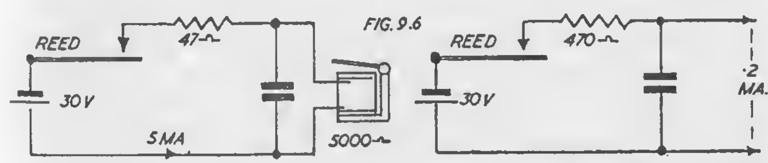
The effective action of a resonant reed is that of a relay with a high selective grain. That is to say it is capable of switching a relatively high output power with a very low level A.C.

power input (at a selected frequency only). The power gain may be of the order of 300 : 1 or more. At the same time this relatively high current carried by the reed and its fixed contact can cause trouble due to burning, arcing, etc., resulting in an increase in contact resistance or failure of the contact as a conductive switch. Improving the contact performance of the reeds themselves by plating with a contact material (e.g. rhodium or gold) is not necessarily a complete answer for plating may induce hydrogen embrittlement and affect the "fatigue" life and spring characteristics of the basic material (normally a high quality spring steel).

The actual current carried by the contacts (reed and fixed contact) is considerably higher than the nominal operating current of the relay itself, due to the low-duty cycle involved. Thus with a 10 per cent duty cycle and a relay drawing 5 milliamps, peak current values of $10 \times 5 = 50$ milliamps will be carried by the contacts. Also in a typical relay circuit the resistor (Fig. 9.4) is inherently limited to a relatively low value (typically 47 ohms), in order to obtain the necessary current through the relay coil to operate it.

The position with "relayless" operation is very much better. Here the output power handled by the reed contacts is very much lower (typically of the order of 0·2 milliamp) which is fed directly to current amplifier stages in the servo circuit (Fig. 9.6). The resistor value in this case can be relatively high (typically 470 ohms) and peak current relatively low. Hence the contacts are operating under much more favourable conditions, with less chance of failure due to "dirty" or burnt contacts.

FIG. 9.6



The "relayless" circuit also scores on another point, again increasing its reliability. By eliminating the relay completely the three relay contacts which normally carry the even higher servo motor current are removed from the servo circuit—and

with them their chance of failure due to their getting burnt. All three relay contacts are normally used in the servo circuit so that on, say, ten-channel equipment twenty reed contacts and thirty relay contacts are involved—a total of fifty contacts through which current is switched. With "relayless" operation the total of switching contacts is reduced to twenty reed contacts only, and these operating at a very much lower rating than before.

With relayless equipment the receiver virtually terminates with the reed bank, each reed and its associated fixed contact being switching contacts for individual servo circuits. Special servos have to be used embodying transistor amplifier units to accept the low power input and boost it to a level where the current is high enough to switch the servo motor. Normally such an actuator is designed to accept two separate output circuits (i.e. from two different reeds). There may be a danger in such cases, with commonly connected reeds, that accidental operation of both controlling reeds (e.g. during tuning) can result in damage to the circuit. To overcome this "split" reed banks have been developed—i.e. either each reed is separately mounted and insulated, or the bank is split into two halves insulated from each other. In the latter case connections to a common servo are drawn from each half of the reed bank. Other types of transistor amplifier circuits incorporate a "trigger"-switching circuit for input which can accept only one of any two simultaneous signals and can be used with ordinary (not split) reed banks.

CHAPTER 10

MULTI-CHANNEL EQUIPMENT

THE typical multi-channel reed receiver may offer 3-, 4-, 5-, 6-, 8-, 10- or 12-channel operation, depending on the basic circuit and the type of reed bank employed. It is generally supplied as a "matched set" with a transmitter giving the same number of tone switching circuits tunable to matching frequencies. It does not follow that "matched sets" are necessary, however. A 10-channel transmitter, for example, will equally well operate 3-, 4-, 5-, 6-, 8- or 10-channel receivers (provided the tone frequencies are suitable). If the *receiver* has more channels than the transmitter, however, it is reduced in response to the number of transmitter channels available.

Where cost is not the primary concern (the greater the number of channels, almost proportionately the greater the cost of the equipment), selection of the required number of channels depends on the type of model to be controlled and the degree of control required. In the case of aircraft, complete, *direct* control requires a minimum of eight channels, with preferably two more available for elevator trim (see Chapter 12). It is not necessary to go any further, for additional services which can be utilised, such as wheel brakes, nosewheel steering, etc., can be linked to existing primary controls.

In the case of boats, or land vehicles, eight- or ten-channel equipment is generally an unnecessary extravagance. Two-channel gives complete steering control and a further two progressive engine control (or changeover engine control on just one additional channel). Thus three-channel equipment is satisfactory for direct operation of all the necessary *functional* controls. Three-channel equipment, on the other hand is an absolute minimum for being able to fly an aircraft with *direct* signalling—controlling rudder (two channels) and motor speed (one channel)—and without resort to compounding or sequence switching. Five-channel equipment offers a distinct

advantage in providing *direct* elevator control in addition; and six-channel equipment *progressive* engine control on the additional channel. Eight-channel equipment enables direct control of ailerons to be added; and ten-channel equipment progressive elevator trim. For further details on the control requirements of models see Chapters 12, 14 and 15.

With good circuit design and the correct choice of components the multi-channel reed transmitter-receiver combination is extremely reliable. The particular advantages of "tone" receivers in general have already been described (Chapter 2). Multi-tone signalling and decoding by the reed bank adds little complication on the electronics side. Relay performance adjustment is far less critical since each relay is being operated in either a fully "on" (pulling in under maximum current) or fully "off" condition (circuit broken by the reed stationary). Apart from the fact that initial adjustment is required for each separate tone channel, the principle of setting up and adjustment is simpler than with single-channel equipment.

In the case of conventional receivers employing relays, each relay is controlled by one reed and has three contacts available for controlling the switching of the servo circuit, the armature (sometimes called the common or centre connection), and the N.O. (normally open) and N.C. (normally closed) contacts. Connections used depend upon the type and design of actuator. Any one (or more) relays could be used to switch an escapement, using the armature and N.O. contacts to wire to the escapement circuit, just as with single-channel hook-up. It is usual, however, to employ multi-servos as actuators.

The majority of these are designed to utilise all three relay contacts and to be operated off two channels (see Fig. 10.1). That is to say, the servo connects to two relays for the purpose of switching independently one way or the other. Internal contact switching on the servo itself can then provide a positive stop at the end of its travel (in either direction), switching off the motor so that it is drawing no current in "holding" a control position. On release of signal another circuit "made" by the relay armature dropping out then causes the servo motor to drive in the other direction to self-centre.

There are many other possible arrangements, but the above is the more usual, and preferred. The same type of servo is

FIG. 10.1

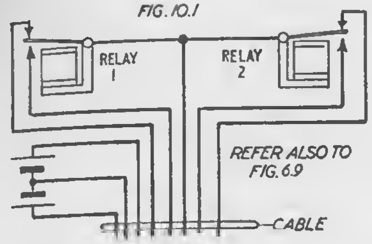
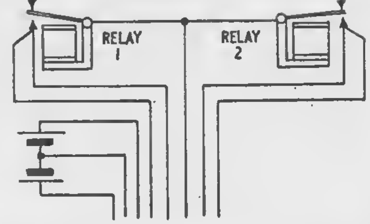


FIG. 10.2



usually readily adapted to "progressive" action by a simple modification of the connections, as shown in Fig. 10.2. Here the servo uses only the N.O. contacts of the two relays. Momentary signals on one relay will cause corresponding momentary movements in one direction, up to the limit of travel. The servo will thus stop in any "inched" position with the motor switched off and drawing no current. Signals on the other relay will "inch" the servo in the other direction.

Other multi-servos (and some single-channel servos suitable for multi-) may work on a simplified principle, dispensing with printed-circuit switching in favour of holding "full" control positions against a slipping-clutch action with spring self-centring. It is necessary to know the complete operating characteristics of a servo in order to be sure of the correct connections to a multi-channel receiver relay or relays. Explicit wiring instructions are normally supplied with each servo. It is preferable to use multi-servos specified for, or known to be suitable for, a particular receiver to be on the safe side. This ensures, for one thing, that the relay contacts are suitable for carrying the servo-operating current (provided the servo is not powered by a servo battery voltage in excess of the maximum specified).

Connection is thus largely a matter of the mechanical job of wiring. Selection of which channel to use for a particular service is largely arbitrary and there is no overall standard. Logically, and particularly with a large number of channels available, it would seem sense to separate "paired" control signals by as wide a spacing as possible to avoid any possibility of interaction between adjacent reeds. Thus, for example, with a 10-channel, channels 1 and 6 would appear a good choice for rudder, 2 and 7 for elevator, and so on, giving the

widest possible spacing between paired signals (i.e. signals controlling the same servo, but in opposite directions).

In practice, this is seldom done. One of the main reasons is that with 8-, 10- and 12-channel equipment, simultaneous control is usually made available in two groups of 4, 5 or 6 signals, respectively. There is then a practical need to have certain controls in one group and certain in the other—virtually the controls which may *need* to be operated simultaneously. Since rudder and ailerons have a similar control effect, these can fall in the same group. Rudder and elevator, however, are the logical "simultaneous" controls, and so these must lie in different groups. This rather restricts the allocation of any remaining services and so typical allocation of relays to the various control services is as shown in Fig. 10.3. Of the alternatives, the simple numerical sequence is often followed (e.g. 1 and 2 for rudder, rather than 1 and 3, and so on). One

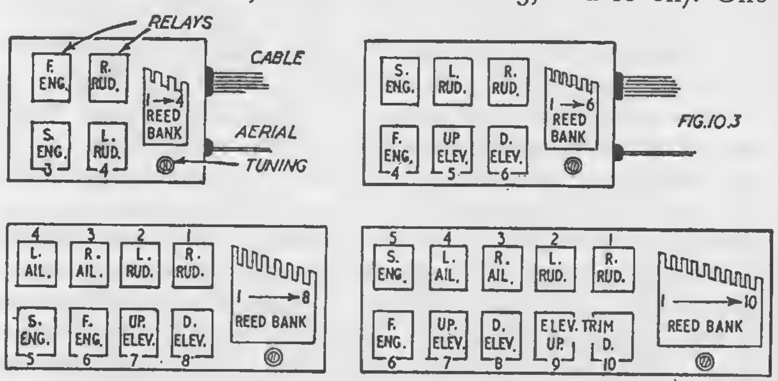


FIG. 10.3

particular reason for this is that the most likely point where "overlapping" or interference between adjacent reeds could occur with simultaneous signalling is usually in the middle reeds of the bank. It is as well, therefore, to allocate these to control services which would normally never be operated simultaneously (e.g. engine throttle and aileron).

There may also be another reason for a definite pattern of relay allocation. The transmitter tone signalling on multi-channel work is normally done with lever-type switches arranged with left-right movement for turning controls (rudder and ailerons) and up and down movements for elevation and trim controls (elevators and motor speed).

It does not always follow that *each* of the circuits wired to the various switches is tunable over the full range of tones covered by the reed bank. Thus by disregarding a particular manufacturer's instructions in allocating the relays it may only be possible to bring in a certain relay (and associated control) in a "wrong" position as regards keying from the transmitter.

A typical multi-channel reed receiver is provided with a single tuning control. All that is necessary to do to tune the receiver is to switch on both transmitter and receiver, hold on any one transmitter tone signal and then turn the tuning control until a reed starts to drive (vibrate). This will be heard as a singing note. The mid-position is found for tuning, i.e. the tuning slug turned one way until the reed stops driving then back again as far as possible in the other direction until the reed again stops driving. The mid-position between these two extremes of adjustment is then correct.

The transmitter requires two separate tuning techniques. Usually two trimmers are provided controlling the oscillator and RF output; and a further set of controls consisting of potentiometers, one for each tone channel. To assist in RF tuning an indicator light is usually incorporated in the circuit as a visual guide. Alternatively a meter may be used, plugging into the circuit and adjustment made to realise specific working current figures. The oscillator trimmer (see Fig. 10.4) normally requires adjustment for minimum current, shown by the indicator light going out, or minimum meter reading, and then advancing a specified amount. The amplifier trimmer is then adjusted for maximum output (indicator light showing peak brightness, or maximum meter reading).

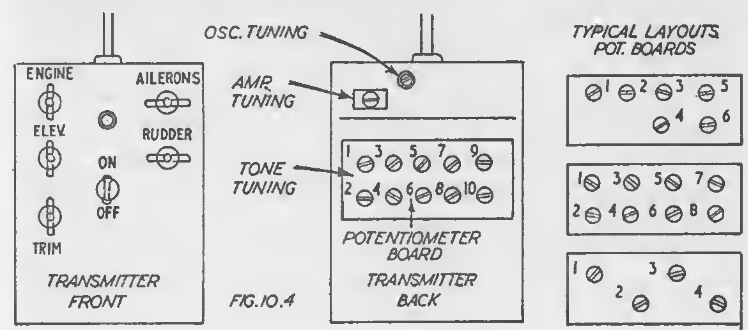


FIG. 10.4

Adjustment of the individual tone circuits then follows. In the case of a non-simultaneous transmitter, one control is held on and the corresponding potentiometer adjusted until the appropriate receiver reed commences to drive. The range of adjustment over which the reed continues to drive is found and the tuning control set to the mid-position. This procedure is repeated for each channel in turn. Check, however, that the reed freely responds to bad "blipped" keying of the appropriate transmitter tone. The transmitter tone circuit adjustment which may appear to give the *strongest* reed response with signal held on during adjustment may not drive the reed at all when the same signal is subsequently "blipped" on and off.

With a multi-tone transmitter capable of simultaneous operation the procedure is essentially the same except that whilst adjusting the individual controls in one group any one control in the *other* group is simultaneously held on.

As a final check, tuning should be repeated, if necessary, at range (see Chapter 16). With initial adjustment, particularly, there may be a possibility of driving both reeds on the same control at the same time, causing damage to the contacts. This can be avoided by disconnecting the servos and simply listening to the reed tones and observing which particular relay is operated in the bank. Plug-and-socket connections between receiver output leads and servo wiring make disconnection and re-connection easy. There would normally be no need to disconnect servos for a final range check which, in any case, is preferably (but not essentially) carried out with the engine running and operation must be judged by the response of the control movements. This technique may also be necessary in the case of boats where accurate tuning can only be carried out with the boat in the water (see Chapter 16).

CHAPTER 11

"MULTI" PROPORTIONAL CONTROLS

MULTI-CHANNEL control systems as described in Chapters 9 and 10 are specifically intended for "bang-bang" controls (or progressive trim controls). That is to say a full "on" control position is selected, the *degree* of movement achieved being entirely dependent on the mechanics of the linkage involved. Given enough control channels this is a perfectly satisfactory method of controlling any type of model in practice although there may be a certain lack of smoothness in performing certain manœuvres and such factors as *rate* of turn, roll, etc., can only be varied by blipping the controls and thus completing the manœuvre "in steps" as it were. In spite of the proven reliability and scope of conventional multi-channel systems, therefore, *proportional* control represents a further field of development.

Proportional control can be obtained with single-channel systems by "pulsing" the transmitter signal. Obviously with multi-channel equipment the principle of "pulsing" can again be applied as a simple means of obtaining "proportional" control response. Thus one tone may be pulsed to obtain proportional rudder control, and a second tone pulsed to obtain proportional elevator control; and so on. Systems of this kind can and do work in practice, although seldom carried beyond two-channel signalling with any degree of reliability. Where this is done it is an obvious advantage to have the two pulse-controlled signal channels available simultaneously (for simultaneous proportional operation of rudder and elevators) and design the transmitter circuit accordingly. This is a feature of certain commercial equipment. For the home constructor, pulsing methods and types of actuators follow exactly as for single-channel (Chapter 8).

The more sophisticated proportional-control systems, however, normally start with the "dual-proportional" system

developed by Dr. Walter Good of America (and often known as the WAG system, after the initials of the originator). Here a variable-tone signal is used (e.g. variable between 100 cycles per second and 500 cycles per second), with provision for the transmitter to vary both pulse *width* and pulse *rate* (see Fig. 11.1). The receiver embodies a pulse-width detector designed

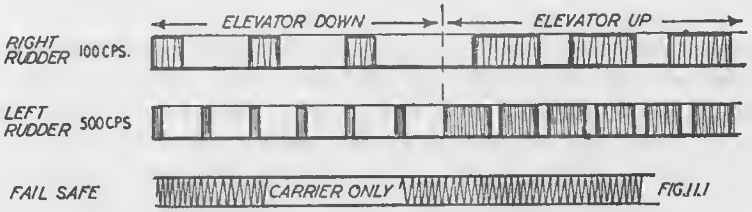


FIG.11.1

to give a positive output when the pulses are broad, and a negative output with narrow pulses. This output is fed to a relay stage valve resulting in the relay pulling in with positive output and dropping out with negative output. This relay, in turn, controls the elevator servo giving proportional movement corresponding to the mark : space ratio of the pulse transmitted.

Also incorporated in the receiver is a pulse *rate* detector which distinguishes between pulses at the lower frequency and those at the higher frequency. The output is connected to a rudder servo in a similar manner as before. Low frequency pulses (100 cycles per second) correspond to full right rudder and higher frequency pulses (500 cycles per second) to full left rudder. By varying the pulse rate between these extremes any proportional rudder position can be selected. Pulse width and rate controls can both be transmitted simultaneously, and originated by movement of a stick-type control lever, so that simultaneous proportional operation of rudder and elevators is provided.

The WAG receiver circuit (Fig. 11.2) also incorporates a "fail-safe" relay. When no pulsed signal is sent, or the receiver is picking up steady interference, all three relays pull in but the "fail-safe" relay cuts off the servo battery so that both elevator and rudder controls remain in neutral. The second contact of this "fail-safe" relay can be connected to a further

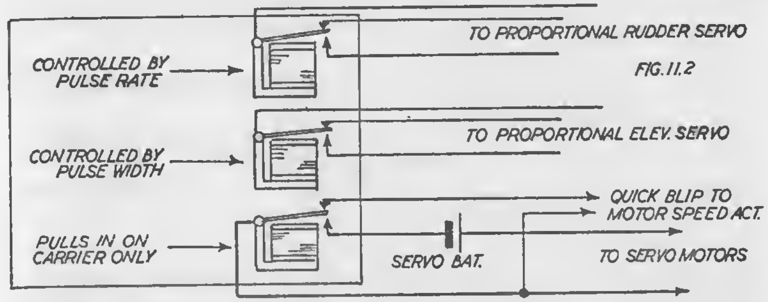


FIG. 11.2

actuator to control engine speed, responding to a "quick blip" signal on the carrier and giving normal "quick blip" action (see Chapter 6). A further "fail-safe" action is provided on the transmitter. This is a button which switches off the tone oscillator. Pressing this button should an emergency occur (e.g. complete loss of control) immediately cuts off the tone signal and leaves just the carrier being transmitted. As noted above this operates the "fail-safe" relay in the receiver and neutralises the controls.

Simple geared electric motor servos can be used with WAG dual-proportional, with spring centring. The system has the advantage, compared with single-channel "proportional" that the control surfaces do not oscillate continuously but move smoothly to their proportional position. Conventional "multi" servos can also be used with WAG with the advantage that return to neutral under "fail-safe" condition can be given by the motor and not rely on a spring return. In this case only very light centring is required—e.g. a rubber band on the motor shaft for centre loading.

Triple-proportional control systems work on a rather different principle. In this case three independent tone channels are used, each of which is independently variable in frequency. The increase or decrease in tone frequency is decoded by the receiver in terms of a plus or minus output voltage. This variation in output can be used to operate three proportional control systems, as above, or on some similar basis.

There are numerous other alternatives on similar lines. Dual-proportional control may be provided on two tones for the critical control surfaces (rudder and elevator), as in Fig. 11.3

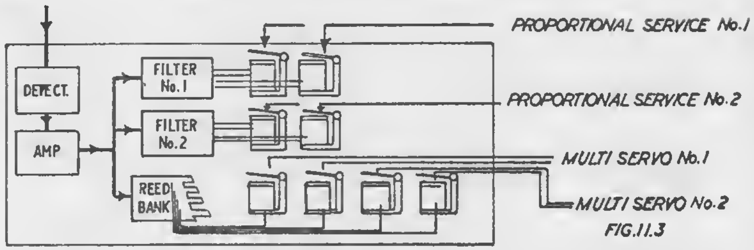


FIG.11.3

with additional tones operating further control services on a "bang-bang" or progressive basis through normal "multi"-circuitry. One of the major troubles likely to be experienced with these more sophisticated systems is interaction between controls. They are, therefore, somewhat limited in application and (with the exception of WAG dual-proportional) normally restricted to experimental development by the more experienced electronic experts rather than suitable for commercial production.

One form of quadruple-proportional control system has, however, been developed as a commercial item, under the name "Space Control." This is basically a two-tone system with a variable frequency controlling rudder on one tone and elevator on the other tone. It differs from other dual-tone systems in that the tones are transmitted alternately. Thus, considering one tone centred at 1000 cycles per second and the other at 2000 cycles per second, the 1000 cycles per second tone is transmitted for 1/100th second, followed by the 2000 cycle tone for 1/100th second, and so on. This establishes a basic repetition rate of 50 per second of two tones. By varying the repetition rate (i.e. the actual time each alternate tone is transmitted) a further control "channel" is made available, capable of proportional variation. Yet another control "channel" can be established by keeping the repetition rate constant and varying the *symmetry* of the alternate signal times—i.e. increasing the time "on" of one relative to the other. This again is capable of "proportional" variation, giving a total of four possible "proportional" control channels (see Fig. 11.4).

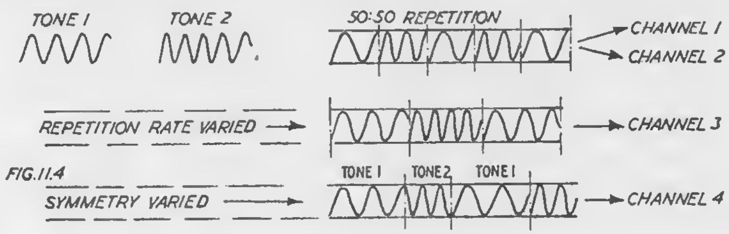


FIG.11.4

It is a common assumption that fully-proportional control systems are preferably to "bang-bang" controls. In practice this is not necessarily so, despite the fact that a pilot controls a full-size aircraft (or any other type of vehicle) by "proportional" control movements. This is because piloting a model from a ground position is quite different to moving as part of the vehicle being controlled. There is an inevitable time lag between actual movement of a model and an *appreciation* of what that movement is, and what following control action may be necessary. It thus needs considerably more practice to master control with a proportional system.

There is also the fact that with any advanced control system a model aeroplane designed to take full advantage of the controls available may have very little inherent stability. Automatic stability, or the ability to recover rapidly to a normal flight path on neutralisation of controls does, in fact, mitigate against manœuvrability. Thus a "fail-safe" system which returns all controls to neutral may not recover the model from a dangerous situation, simply because the model has not enough inherent stability to effect recovery in time. Add sufficient automatic stability to give this desirable feature and it becomes that much more difficult to manœuvre smoothly, demanding even *more* precise control.

Multi-channel systems with "bang-bang" operation of the critical controls are *easier* to fly because only two control positions are possible—control "full on," or neutral. There is not the need to *synchronise* control-stick movements, as with proportional control systems, where control response is infinitely variable (up to the limit of full-control positions). Exactly the same considerations apply to rudder control on a high-speed boat.

There is a further limitation with all proportional control systems utilising "open-loop" servos. An "open-loop" system implies that the mechanical movement of the control surface is proportional to the input current to it (output current from

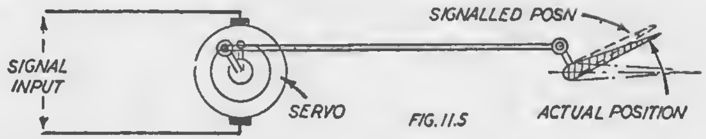


FIG. 11.5

the receiver circuit) (Fig. 11.5). Under actual working conditions, however, aerodynamic loads on the control surface may appreciably affect the amount of movement realised, and even reduce it drastically. This is known as "blow-back." A similar condition may apply to a marine rudder operating in water, at speed. The *actual* control surface movement, therefore, is not strictly proportional to the transmitter control-stick movement (governing the proportional signal). The loss of movement or "blow-back" will also vary with speed of flight (or speed of the model boat through the water).

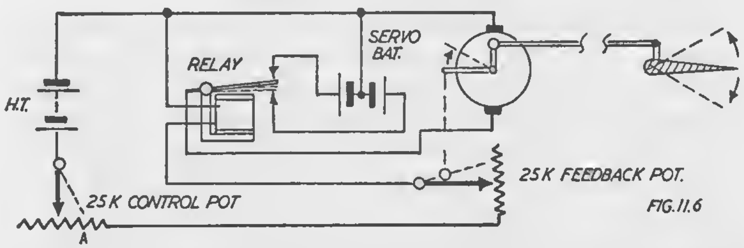


FIG. 11.6

This can only be overcome by adopting a "closed loop" servo system (Fig. 11.6). Here the basis of proportional drive is that the output mechanism (servo) provides some form of feedback which compares the position of the servo with the input signal. Any difference is interpreted as an "error signal" and the existence of this error signal is used to drive the servo to its true proportional position.

In the typical demonstration circuit shown the servo is mechanically coupled to drive a potentiometer. As connected, the servo motor will drive in either direction, according to whether the relay armature is pulled in or drops out. With the armature mid-way between the two contacts the motor is switched off. This is a typical "proportional" set-up.

Assuming, for the sake of example, that the relay pulls in at a little over 2 milliamps and drops out at a little under 2 milliamps, a 2 milliamp input signal to the servo circuit will

maintain a "null" condition (armature mid-way and motor switched off). If now the input signal is increased to 3 milliamps by movement of the input control potentiometer to position *A* resistance in the circuit is decreased so the relay will pull in and drive the servo in one direction. At the same time the servo will drive the feedback potentiometer to increase the value of *its* resistance until such a point where the increase in resistance exactly balances the reduction in resistance given by movement of the control potentiometer. At this point the relay current will have fallen to 2 milliamps again, giving "null" conditions and switching off the motor.

In more general terms, *any* variation of input signal, causing the relay armature to close the motor circuit and drive in one direction or the other, is progressively compensated by movement of the feedback potentiometer movement (driven by the servo) until "null" conditions are established again, when the motor stops. Thus the feedback control (potentiometer) ensures *proportional* movement of the servo output drive relative to the *actual* change in input signal. Any greater or less movement leaves unbalanced resistance and an "error signal" remaining in the circuit to continue driving the servo until the "null" condition is reached.

In a practical feedback circuit the input signal variation is provided by the receiver response to "proportional" signals rather than direct movement of a control potentiometer, with the value of the feedback potentiometer chosen accordingly. Exactly the same working principle applies, however, although it may be necessary to provide some means of preventing over-run of the motor so as to avoid momentary "hunting" of the servo about the "null" point. This can be done by providing a damping signal (e.g. by connecting the motor brush to the free end of the feedback potentiometer) or mechanical or dynamic braking across the servo motor itself.

CHAPTER 12

R/C AIRCRAFT SYSTEMS

DESCRIPTIONS of different aircraft control systems as typical "types" are often hazy and sometimes contradictory. This is somewhat unfortunate, for the model *design* requirements, to take full advantage of a particular system or even to be satisfactory with a particular system, differ appreciably. Thus whilst a particular model may be described as "suitable for single- or multi-" its design characteristics, and possibly size, must inevitably be more favourable for one than the other. It cannot be an "optimum" design for both.

As generally used, the term "single-channel" may be taken to apply to simple single-channel systems, usually rudder only or rudder plus a third (usually engine) control. This is acceptable as a general definition since models of this type require a high degree of free flight stability to recover from any manœuvres into which it is forced by application of rudder. There are no other controls available to provide restoration of a stable flight path—only that inherent stability built into the model.

The term "multi" is used broadly to cover *all* types of control systems where more than one main control service exists—i.e. both true multi-channel operation and multiple-control operation through single-channel cascaded systems or sequence switching. This is not a satisfactory definition since it embraces different design requirements. A compounded system operating off a single-channel radio link virtually demands a model with a good degree of inherent stability so that on release of controls it will automatically right itself from whatever attitude it may be in. A model with *multi-channel* controls will have a best performance with marginal automatic stability, provided enough controls are available to maintain complete control.

A more satisfactory classification of model aircraft types is as follows:—

SINGLE-CHANNEL

(i) Rudder only (using a simple actuator).
(ii) Rudder and engine control (using a compound actuator).
(iii) Rudder, motor and "kick" elevator (using a modified compound actuator).
(iv) Rudder, motor and elevator (up and down) (using cascaded escapements).

SINGLE-CHANNEL PROPORTIONAL

(i) Proportional rudder (with motor speed control possibly also available).
(ii) Proportional rudder-elevator (simpl-simul system).

MULTI-CHANNEL

(i) Three-channel.
(ii) Four-channel.
(iii) Five-channel.
(iv) Six-channel.
(v) Eight-channel.
(vi) Ten-channel.
(vii) Twelve-channel.

MULTI-PROPORTIONAL

(i) Dual-proportional.
(ii) Triple-proportional.
(iii) Quadruple-proportional.

A rudder-only model is a common starting point. With just this single control a surprising number of manœuvres can be performed, including loops and rolls and Immelman turns, provided the model design and trim is satisfactory. The addition of engine speed control adds further scope and also provides a safe means of losing height (by switching to "low" engine speed).

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The addition of further controls to a simple single-channel system is not necessarily an advantage. Certainly neither (iii) nor (iv) should be attempted on a first model and even in the hands of a more experienced flyer may be troublesome with regard to "lost" sequences, particularly (iv). This is because of the time lapse in selecting a particular control required.

Basically, single-channel radio control is strictly limited in scope. It is quite good in calm weather, when the full range of manœuvres possible with the particular model design can be exploited. It becomes more and more limited in practice with increasing wind and drift, when most of the time may be used in controlling the model to keep headed into wind. A "down" elevator control would be helpful in diving a model into wind to increase penetration under such conditions, but is not essential. With practice a controlled "dive" can be produced by rapidly blipping on alternate rudder producing a shallow S-like flight path about an average direction into wind. The loss of height accompanying a rudder-induced turn produces the required loss of altitude.

This loss of height resulting from turns with rudder-only control is a major limitation to smooth flying performance. If the rudder is held on the model will turn, drop its nose and go into a spiral dive. To produce a "normal" turn without excessive loss of height it is therefore necessary to "blip" the required rudder signal on and off. The model will still lose some height, but entry into a definite spiral dive can be avoided and the radius of the turn controlled by the timing of the "blipped" signals.

Coming out of the turn (rudder neutral) the model will have excess speed and tend to zoom—which is a typical characteristic of a rudder-only model. It may be necessary to blip on opposite rudder momentarily to kill a stall. This "zoom" tendency will also be directly related to the design. The more the model follows normal free flight layout (and thus the higher its automatic stability), the more it is likely to zoom. This can be partially offset by trimming the model slightly under-elevated (compared with normal free flight trim), but this will only increase the tendency to drop the nose in a turn and build up even more speed. Adjusting the design layout to produce a model with less tendency to zoom will usually

result in a considerable reduction in automatic stability or recovery power with neutral rudder, making the model that much more tricky to trim and fly.

Another common practice is to under-elevate the model still further for windy weather flying, mainly to increase the flying speed and penetration. This makes turn control even more critical and limits manœuvrability. To perform a loop, for example, a rudder-only model relies on building up excess speed by being deliberately held in a spiral dive. The rudder is then centralised just as the model is turning into wind when it straightens out and the induced "zoom" carries it right over in a loop.

The model will not complete a loop if it is grossly under-elevated. Some *designs*, too, will not readily loop in this fashion but perform a half roll at the top of the loop and recover the right way up (Immelman turn). Other designs may be capable of both a complete loop with enough speed built up in a spiral dive; and half roll off the top of the loop for an Immelman turn if the speed is slightly less. With the type of trim required to perform such manœuvres the model will usually "kite" or zoom badly under normal rudder steering control in windy weather.

A roll is performed with a rudder-only model by building up speed again in a spiral dive, straightening out crosswind, giving a momentary blip of rudder one way and then holding on rudder the other way until the manœuvre is nearly completed. Some designs can be made to roll in this fashion, others not. It usually requires an under-elevated trim. It will be obvious that manœuvres in both the looping and rolling plane are rather "hit or miss," and possibly require different trims to execute, again emphasising the limitations of rudder-only control. Its chief attraction is that it is simple to install, requires a minimum of capital investment for radio gear and a straightforward easy-to-build model. It is an ideal "trainer" for learning more about radio-controlled aircraft, provided it is flown in calm conditions. It is also adaptable to a wide range of model sizes although there is a definite *optimum* size (especially for beginners) of about 48 inches wing span, powered by a 1·5 c.c. motor. This gives a model which is large enough not to be too critical on power, adjustment or control, but not too large

as to be cumbersome and unnecessarily bulky. Smaller models may be attractive but they are much more tricky to fly, more difficult to fly *smoothly*, and far more susceptible to being upset by winds.

Single-channel *proportional* control systems would appear to offer more scope, especially the simpl-simul system offering both rudder and elevator control. Unfortunately systems of this type are not produced commercially (in this country) and so practically all the necessary modifications to standard single-channel equipment has to be home-built (see Chapter 8). Not everyone is capable of the high standard of workmanship required to ensure consistent, trouble-free operation, nor are such systems themselves entirely foolproof.

A model fitted with proportional rudder control would be based on normal single-channel requirements—a design with good inherent stability for self-recovery. With proportional rudder-elevator, however, where the model is flown under "joystick" control all the time the stability margin can be sacrificed in favour of greater manœuvrability. The model may even approximate in layout to an advanced "multi" design. This is not a satisfactory choice, however, since the rudder is still the main turning control in the absence of ailerons and as a general rule any model which relies on the rudder as its sole turning control *must* have sufficient inherent stability to recover a normal flight path with neutral control positions. Otherwise it is all too possible to lose control completely following over-control, with catastrophic results.

Multi-channel radio provides the most positive, and generally the most reliable method of control of aircraft. Scope offered increases with the number of channels available. Five-channel radio is a minimum for *comprehensive* control; and eight-channel a minimum for *complete* control.

Basically the scope offered by multi-channel equipment is as follows. Using up to *four* channels model design requirements are virtually the same as for single-channel operation, with a somewhat similar restriction on the variety of manœuvres possible. Such systems, however, are generally *safer* to fly than single-channel equivalents (in the matter of control services available) and control operation is more foolproof because of direct and *faster* selection of individual control

movements required. It is easier to perform "blipped" turns and dives with rudder-only with two-channel "multi" than with a single-channel rudder-only system, for example.

Five-channel "multi" enables the highly desirable combination of elevator and rudder controls, with the additional channel available for engine speed changeover. Six-channel gives the same with "progressive" engine control. This gives a model with full manœuvrability in the looping plane, and elevator control to correct "zoom" and initiate a dive to improve penetration. Inverted flight is also possible.

Turning without loss of altitude still demands blipping on the rudder signal, but becomes easier since this is directly signalled. Elevators, again, can correct any change in height. The only basic control lacking is in the rolling plane. It may be possible to perform rolls (of a sort) using "rudder-only" technique—except that speed can be built up by diving; and the absence of roll control (ailerons) usually demands a certain amount of "free-flight" stability in the design, e.g. a reasonable dihedral angle and design layout still favouring the high-wing monoplane.

Eight-channels allow aileron control to be added and the design can be "de-stabilised" accordingly for maximum manœuvrability. The model is then virtually flown all the time by the controls through a complete range of manœuvres with immediate correction available for *any* displacement or departure from normal flight path. It is no longer *necessary* for the model to be inherently stable although it is strictly advisable that a first model of this type should be stable enough to correct itself "hands off" (i.e. all controls neutral).

Thus typically successful designs for eight-channel (or more) range from the conventional high-wing monoplane to low-wing monoplanes. Dihedral is appreciably less than normal for "free-flight" stability, the actual amount depending largely on the inherent stability margin aimed for. Dihedral is a strong stabilising feature in design, but acts against manœuvrability. In particular it makes the model less prone to assume a stable flight path in inverted flight.

The more advanced aerobatic models generally favour the low-wing monoplane layout as being more readily capable of trimming "zeroed out." Basically this means that the neutral

control (or "hands-off" free-flight trim) leaves the model continuing in the same attitude as it was forced by the previous elevator control movement—e.g. in a climb, dive or level flight. To diverge from this path, elevator control must again be used. Any model possessing inherent stability will have one "hands-off" flight path only, depending on its initial trim, and tend to revert to this from any attitude once elevator control is neutralised. The time it takes to revert to "hands-off" trim is dependent on the margin of stability. A very stable model will quickly correct itself. One with less stability will take longer.

Zeroed-out trim is a distinct advantage for smooth flying since continual correction is not required to maintain a flight path distinct from "hands-off" trim. The latter results in having to fly a climb or dive in "steps," blipping the elevators to act as a trim control. Since there is no reserve of stability opposing further displacement with zeroed-out trim, too, response to control movement is faster and again smoother.

It is virtually impossible to incorporate a perfectly balanced zeroed-out trim in any design. It may apply during normal flight, for example, but when inverted the elevator will almost certainly have to be "blipped" to trim the model to maintain level inverted flight. Hence one further control is really necessary for complete control—elevator trim. This is best made available as a *progressive* control, calling for two more channels.

Ten-channel equipment, therefore, provides all the control required, and represents virtually the ultimate for model aircraft flying. *Twelve-channel* equipment is made and offers further secondary services—e.g. flaps, wheel brakes or wheel steering. Most of these services which could improve performance, however, can be incorporated with a ten-channel system. Nosewheel or tailwheel steering can be mechanically linked to operate off the rudder servo. Wheel brakes can be mechanically linked to operate off the up elevator trim servo. This is quite logical since neither auxiliary service interferes with the main service, nor are the linked controls ever required independently. Mechanical linkage of this nature also saves the weight and cost of two additional servos.

The main divergence between the "single-channel" design and the "multi-channel" model begins once aileron controls

are incorporated. The rudder is still essential as a primary control but, with ailerons also available, practically all the turning in flight is done with ailerons only. The rudder is seldom touched, and the "viciousness" of normal turn control is lost as a consequence. Anything *less* than rudder, elevator and ailerons operated independently (with preferably engine speed also for safety) cannot give the same degree of control and manœuvrability offered by conventional multi-channel equipment.

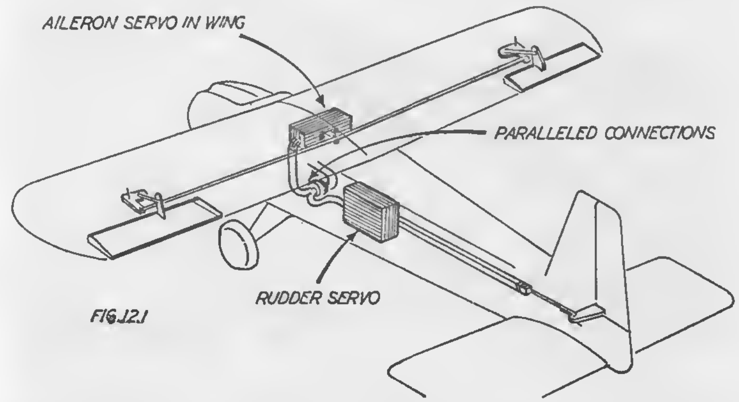
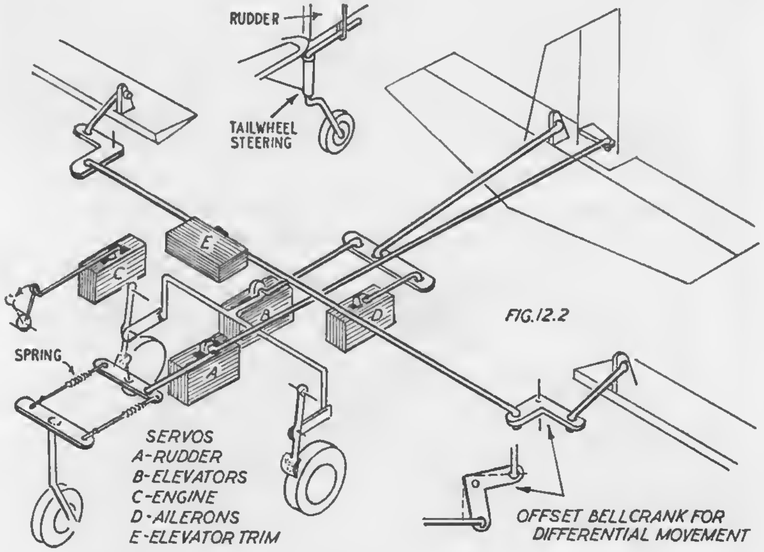


FIG.12.1

The only valid reason for accepting less than this is the very real one of cost. Eight- or ten-channel equipment is very much more expensive than the simpler "multi" installations utilising less channels. In such cases, however, it is strictly necessary to compromise and accept the fact that there will be resulting limitations. Table II (page 113) and Fig. 12.2 summarise possibilities with the full range of multi-channel equipment and specific recommendations.

There is the interesting possibility with up to six-channel equipment of utilising aileron control parallelled with rudder. Here a separate servo for operating the ailerons is electrically connected in parallel with the rudder servo. Hence operation of rudder simultaneously produces corresponding aileron movement, signalled by the same channel (see Fig. 12.1). This does, in fact, improve the performance of some manœuvres. In others, rudder and ailerons may be acting in opposition to that required during part, or whole, of the manœuvre. It is by

no means as good as having separate, independent rudder and aileron controls, but can often prove better than rudder control alone.



Coupled elevator and rudder can also be used with *single-channel* rudder-only. In this case it would again be preferable to use a motorised self-centring servo to operate the ailerons and couple a switcher as in Fig. 7.7 to the main rudder escapement to "parallel" the action of the aileron servo with rudder switching. Coupled elevator and rudder has also been used with some success on dual-proportional systems.

The multi-proportional systems are virtually in a class by themselves, demanding considerable skill and experience on the part of the pilot to maintain full and complete control (see Chapter 11). The amount of skill required would depend on the stability margin available on the model. The lower the "hands-off" stability the greater the necessity to maintain full control of the model all the time and be able to mentally "fly with" the model to maintain proper synchronisation of control movement. Given the required amount of piloting skill a multi-proportional model with rudder, elevator *and* aileron control (the latter not necessarily proportional) *should* be able to

out-perform a similar model design with eight- or ten-channel equipment operating on the "bang-bang" principle. It would only normally do so, however, in the hands of an extremely competent pilot.

TABLE I. RECOMMENDED SINGLE-CHANNEL R/C AIRCRAFT SYSTEMS

(See Figs. 7.1, 7.2, 13.1, 13.2 and 13.6 for installation details, etc.)

Control(s)	Actuator	Model Span	Model Engine*	Design
Rudder (sequence)	S-N escapement	42″–48″	1·0 to 1·5 c.c.	high-wing monoplane. 7–10 degrees dihedral. Good free flight stability. Trim adjusted by packing tail-plane. Under-elevate windy weather.
Rudder (selective) plus Engine Speed	Compound escapement	48″–54″	1·5 to 2·5 c.c.	
	S-N escapement *or* 4-position escapement	54″–60″	3·5 c.c.	

*Diesel or glow motor

CHAPTER 13

R/C AIRCRAFT INSTALLATIONS

In the case of aircraft, weight is critical as affecting the balance and trim. The actual *increase* in total weight of the model as a result of fitting the radio gear is relatively unimportant compared with optimum *positioning* of the component weights so that the design balance point is maintained. As a general rule, therefore, all the main component weights—receiver, actuators, batteries, should be positioned or grouped in the fuselage immediately under (or over) the wing and around the design balance point, unless the design is *specifically proportioned* to carry weights (e.g. batteries) in the nose section.

One of those general rules which nearly always works out in practice—with both model and full-size aircraft—is that a new aircraft usually comes out tail-heavy. It is always as well, therefore, to err on getting weights too far forward rather than too far aft. At the same time no substantial weights should ever be located very far from the balance point or centre of gravity of the aircraft as their inertia could adversely affect performance during manœuvres.

In a typical model R/C aircraft fuselage the cabin area is left open to accommodate the radio gear. The front face of the cabin is normally formed by a stout (ply or ply-faced) bulkhead, with a similar bulkhead at the rear of the cabin. The balance point of the model will correspond to about one third back from the front of the cabin.

A good installation is shown in Fig. 13.1. The receiver is strapped to a ply false former, cushioned with foam rubber, and fitted by sliding into channels in the sides of the fuselage formed by cementing balsa strips to the inside of the sides. This divides the cabin space into two compartments. The front compartment is then available for carrying the batteries. These can be wrapped in foam rubber and simply pushed in place, making sure that they are tight enough a fit not to jump

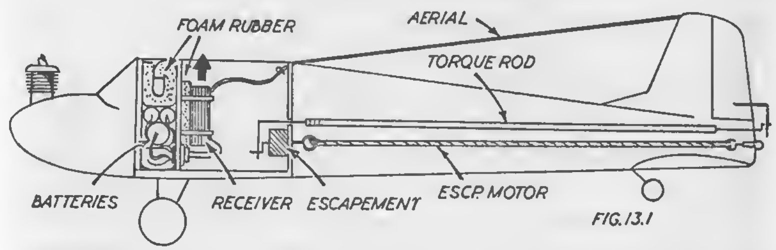


FIG. 13.1

about, or fitted in a special battery box or built-up balsa box.

The actuator for the rudder control is then mounted on the rear cabin bulkhead, transmitting movement to the rudder via a hard balsa torque-rod with bound-on wire end fittings, as shown. The rubber motor for the actuator runs parallel to the torque rod, with a winding plug at the rear enabling the rubber motor to be wound with a wire hook fitted in a hand-drill.

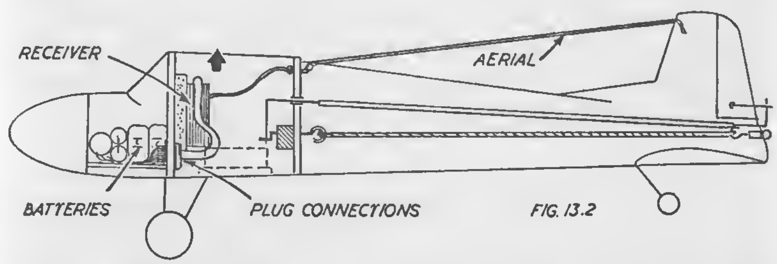


FIG. 13.2

An alternative scheme is shown in Fig. 13.2. Here the receiver, wrapped or protected with foam rubber, is mounted either vertically against the front bulkhead, or horizontally on the cabin floor. The batteries in this case are mounted in the compartment forward of the front bulkhead. The rudder escapement is mounted as before but a second escapement may also be fitted to operate the engine speed control. This second escapement is mounted vertically with a short, vertical motor wound from a plug fitting the bottom of the fuselage.

In both cases the receiver is mounted *behind* the batteries (so that the batteries cannot be thrown forward against the receiver in a crash); protected against vibration and shock by foam rubber mounting; and the main weights (receiver and batteries) are grouped around or forward of the balance point.

The escapement is also mounted well forward, even if this does mean it working via a lengthy torque-rod.

Plug and socket connections permit of ready disconnection of the batteries for replacement. Receiver and actuator leads can be wired to a common socket or to common or separate plugs fitting a socket. Wiring should be collected neatly into cable forms rather than left hanging about. Wiring should also be kept short, to minimise current losses due to the resistance of wiring, but never *taut* which would throw strain on the end connections and cause early failure under vibration. The on-off switch should be located in a convenient place on the fuselage side *opposite* to the engine exhaust where it cannot get sprayed with oil.

There are, of course, many possible variations on these basic layouts but few, if any, offer any overall advantages. The escapement is sometimes located in the rear of the fuselage for convenience of coupling to the rudder. This is *not* good practice. It is weight in the wrong place. It means long leads to the escapement coil with the possibility of a surprisingly high voltage drop. It also brings the "winding" end of the rubber motor into the cabin where it is less convenient to unhook and wind.

There is no objection to having to use a long balsa rod as a torque-link. In fact it is a highly practical method of linkage and certainly preferable to a solid wire rod or metal tube which would be much heavier and also represent a possible source of "noise" to interfere with the operation of the receiver. This question of self-generated electrical interference is an important one. Any metallic parts in the linkage which rub over and move relative to each other can generate "noise," often to a sufficient degree to be picked up as a spurious signal by a sensitive receiver and cause false operation of the control. This possibility can be overcome by insulating one metal part with respect to its contacting member—e.g. with thin plastic tube or insulated sleeving, as in Fig. 13.3. An alternative method is "bonding" or direct electrical connection of the two metal parts with a flexible lead soldered between them. This bonding lead—usually flexible braid—must have sufficient "slack" so as not to impair the free movement of the linkage concerned.

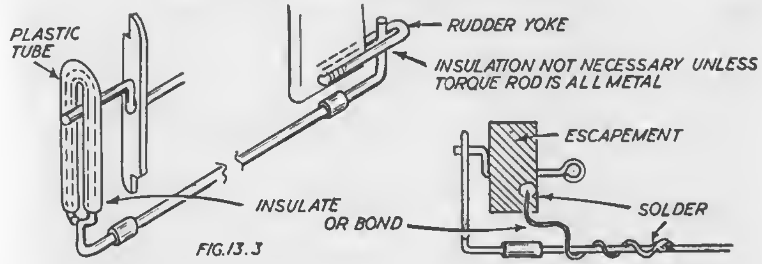


FIG. 13.3

All points in the linkage where metal rubs metal, or any other part of the model where metal can run against metal under engine vibration, should be insulated or bonded to avoid "noise" and the possibility of self-generated interference. Long horizontal runs in wiring should also be avoided as possibly interfering with aerial efficiency when the aerial is run parallel to them (the aerial wire normally being taken out of the back of the cabin and led to the top of the fin). For the same reason the aerial should emerge as a separate wire and never be cabled in with other wiring, or taken through a common plug connection. Where parallel wiring runs to the aerial are unavoidable, then the simplest method to eliminate interference would be to run the aerial spanwise to a wing-tip, i.e. at right-angles to the (possibly) offending wiring.

Other sources of interference are relay contacts, switching contacts on escapements or servos, and electric motors (where servos are used). Any actuator coil connected to relay contacts represents an inductive load which, on "break" tends to produce a surge of voltage and thus a considerably higher current than that normally carried by the circuit. This can lead to arcing at the contacts as they "break," generating "noise" and also possibly pitting or damaging the contacts.

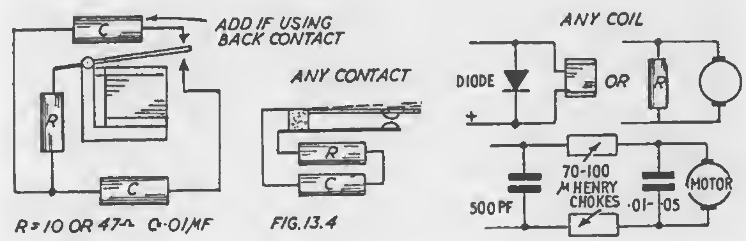


FIG. 13.4

Arc suppression is given by connecting a capacitor or diode directly across the contacts points; or a capacitor and resistor in series across the points. Typical methods and values are shown in Fig. 13.4. Note that where the back contact of a relay is employed this also needs suppression.

In the case of servo motors, adequate suppression can often be given by connecting a 47-ohm resistor across the motor terminals. Other methods include earthing each terminal to the motor body via a capacitor. In bad cases more positive suppression is produced by using two chokes, one in each motor lead, and two capacitors as shown in the bottom right diagram.

Where servos are employed instead of escapements, as on multi-channel installations, the similar installation principles apply. Generally there is room in the fuselage to group the receiver and batteries in separate compartments on either side of the front bulkhead, as in Fig. 13.5. Rudder, elevator

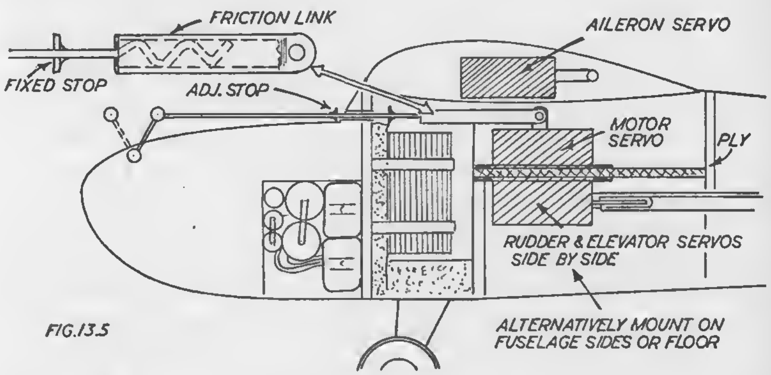


FIG. 13.5

and engine control servos should then be grouped in the cabin as close as possible to the balance point of the aircraft. They may be fastened to a ply mount, or to the fuselage sides or floor, as most convenient. In either case a ply base should be used as the mount and the servo fastened to this mount with screws, but insulated from direct contact with the ply with a thin sheet of foam rubber. This gives a shock-resistant mounting to insulate the servo against direct vibration transmitted to the fuselage by the motor.

Where an aileron servo is also employed this is invariably best mounted in the centre section of the wing itself (see Figs.

12.1 and 13.5). The servo and its linkage is thus incorporated as an integral part of the wing, needing only electrical connection on assembly (e.g. via a plug and socket) to connect to the radio circuit and servo battery. There is no advantage in having a fuselage-mounted aileron servo with detachable aileron linkage.

Motor-speed control via a push-pull action is worth separate mention. Practically all engine-speed controls work on a barrel-type throttle rotated by means of an arm. This throttle may or may not be interconnected with an exhaust flap by mechanical linkage. In either case the basic movement required is fore and aft travel of the operating arm.

This arm has two end positions, corresponding to "fast" and "slow" running settings. These end positions may be established by adjustable stops on the engine itself, in which case the degree of movement required will be determined by the setting of these stops and the length of the control arm. More usually, only one stop will be fitted for setting the "slow" position. Many engines have no stops at all for the "end" positions.

Rather than attempt to match the push-pull movement available from the actuator to the exact linear swing required on the throttle arm it is easiest to arrange for a friction link in the wire linkage, as shown in Fig. 13.5. The total push-pull travel available should be arranged to be in excess of that required. One fixed stop and one adjustable stop on the wire link then permits the *exact* travel required to be set up, excess movement of the servo being expended in expanding or contracting the friction link. A suitable friction link can easily be made by flattening slightly a short length of brass or copper tube and bending the end of the 18-gauge wire rod to provide a friction grip in this flattened tubing.

Fig. 8.6 shows a typical servo installation for simpl-simul where again the motor is mounted well forward and the rudder crank is operated by a balsa torque-rod and wire-end fittings bound in place. The rudder and elevator yokes are bent from 18-gauge or 20-gauge wire, sewn or bound in place. Details of other control linkages using standard or recommended practice are summarised in Figs. 7.1 and 7.2. Note particularly how the rudder can be operated via a control horn as an

alternative to a crank where a push-pull movement is available from the actuator. Separate (multi-channel) elevator and aileron controls are always operated via push-pull action and control horns. Where a push-pull action is required from a normal crank-drive escapement this can be obtained by mounting the escapement vertically (e.g. for engine-throttle control) or by using intermediate linkage as in Fig. 13.6.

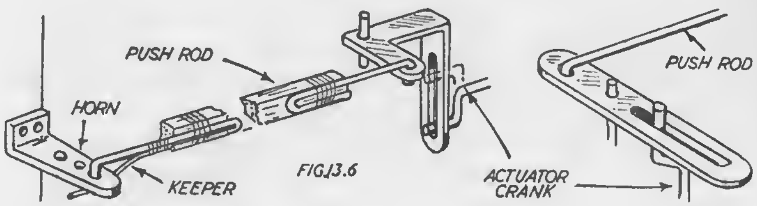


TABLE II. RECOMMENDED MULTI R/C AIRCRAFT INSTALLATIONS

(See also Fig. 12.2)

Receiver	Controls	Model Span	Model Engine	Design
3-Channel	Rudder R & L Engine Speed (changeover)	50"–54" 54"–60"	2·5–3·5*†c.c. 3·5†c.c.	High-wing monoplane. Generous dihedral (6–8 degrees) Good free-flight stability.
4-Channel	Rudder R & L Engine Speed (progressive)	50"–60"	3·5†c.c.	
5-Channel	Rudder R & L Elevator Engine Speed (changeover)	54"–60"	3·5–5·0†c.c.	High-wing monoplane with reduced dihedral (about 5 degrees). Symmetrical or semi-symmetrical wing. Some reserve of free-flight stability.
6-Channel	Rudder R & L Elevator Engine Speed (progressive)	54"–72"	3·5–6·0†c.c.	
8-Channel	Rudder R & L Elevators Ailerons Engine Speed (progressive)	60"–72"	0·29 to 0·35† cu. in.	High-wing, low-wing or shoulder-wing with minimum dihedral. Symmetrical or semi-symmetrical wing section. Zeroed-out trim.
10-Channel	Rudder R & L Elevators Ailerons Engine Speed (progressive) Elevator Trim	70"–84"	0·35 to 0·49† cu. in.	As for 8-channel with low wing and thin sections preferred.

*Diesel. †Glow motor.

Note: Additional control services may be obtained thus:
Nosewheel Steering—linked to rudder servo.
Tailwheel Steering—mechanical link to rudder movement.
Brakes—linked to elevator servo (elevator "up" to operate).
or to engine speed servo (low speed).

CHAPTER 14

R/C BOATS

The primary control required with a radio-controlled model boat is rudder, either "proportional" or "bang-bang." A self-neutralising action is desirable with a non-proportional system and *essential* for the safe control of high-speed boats. The only other *necessary* control is motor speed, either sequence-switching from "high" to "low" speed, or progressive throttle action. The former can be provided by a compound actuator off single-channel operation. The latter virtually demands "multi" radio equipment with four channels (two for rudder and two for engine speed).

As with aircraft, there are many different *types* of model power-boats. In general they may be classified as electric motor-powered or "engine"-powered (diesel or glow motor). Any particular hull may be suited for either form of power unit, the main difference being that electric-powered boats are normally slow-speed craft whilst diesel- or glow-powered boats are capable of planing (with the right type of hull) and travelling at high speeds.

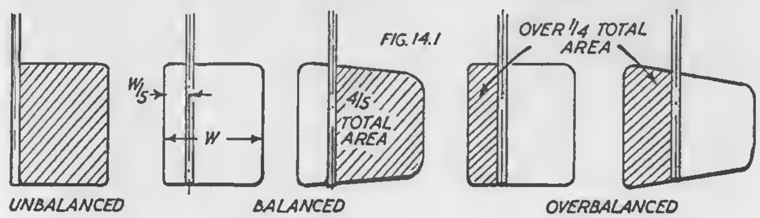
Sizes, too, are to some extent influenced by the power unit. Electric-powered models can be quite small—ranging from as little as 9 inches overall length, up to 36 inches or more. Engine-powered boats usually start from about 22–24 inches length and may range up to 40 inches length or bigger.

Whilst it may be perfectly possible to incorporate simple radio-control gear in quite a small model the performance realised is not always satisfactory. A small model means electric motor power for a start, and consequently a low-speed performance. Being both small *and* slow it may be more influenced by wind and waves than the rudder control. If such a model is selected, therefore, it must be regarded as essentially for "dead calm" operation. Models of about 24 inches in length, and larger, offer considerably more scope and a more realistic

performance. The best size of model is about 32–40 inches long, powered by a 2·5–3·5 c.c. engine.

The steering control is influenced by factors not found in aircraft. In the first place the load on the steering actuator is greater (making a motorised servo a more logical choice than an escapement). Secondly the "reaction time" is much longer. Because of the lower speed longer "control on" periods are required to initiate a turn. This makes control signal "timing" less critical, so that selective sequence switching is quite a practical proposition. There are also the advantages that there is not the same need to "blip" rudder controls rapidly, as with aircraft performing certain manœuvres, nor can the boat develop unstable tendencies when a turn is held on (unless the hull design is unstable). Hull stability becomes an important feature with high-speed craft, particularly in turns. Correct design and trim causes the craft to generate a "bank" or lean inwards with the turn. This banking tendency should not be too pronounced—some high-speed craft literally assume a near-vertical attitude in fast turns—nor should the boat lean *outwards* on turns. Both are unstable reactions which could cause a capsize in roughish water.

Rudder load can be minimised by providing a "balanced" rudder, which is normally done in any case. A balanced rudder has its pivot point some way back from the leading edge (see Fig. 14.1). With a flat section rudder, if the pivot point is approximately one-fifth to one-quarter back from the leading



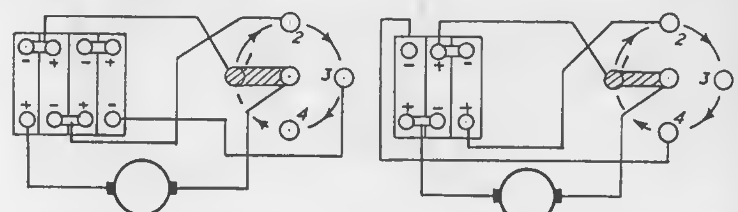
edge the hydrodynamic force acting on the front area will exactly balance and compensate for the hydrodynamic force opposing movement of the rudder. In this condition, operating load required to move the rudder is very light. At the same time, however, the rudder area loses some of its efficiency *as* a

rudder or turning control. Move the pivot point farther aft still and the rudder is overbalanced, needing a force to hold it against turning once it is displaced. Its rudder action now is very weak. Thus too much "balance" is undesirable, but a certain amount of balance relieves the rudder actuator of load. The fact remains, however, that the load required to move an *efficient* balanced rudder is still too high for the average aircraft-type escapement to handle, except on the smaller low-speed craft.

Having motor speed control is more important on a fast boat than on a slow one. Progressive throttle control where the throttle can be "inched" to any position and thus give the full speed range gives most scope with a fast boat. Many diesel or glow motors, however, have only two effective speeds even when fitted with a throttle—"fast" or "slow." In such cases there is nothing to gain by using progressive throttle control. To achieve a full throttle range it is first necessary to select an engine which is capable of giving such a performance.

The usual method of throttle control is identical to that fitted to aircraft engines (see Chapters 6 and 12). Most marine diesels and glow motors are, in fact, water-cooled versions or adaptations of model-aircraft engines and fitted with a flywheel in place of the airscrew.

With electric motors the possibility of speed control is somewhat different. There are several ways of effecting speed-control, one being to arrange to switch, in sequence, various stages of the main battery corresponding to, say,



1-1/4 SPEED 2-HALF SPEED
3-FULL SPEED 4-STOP

FIG. 14.2

1-SLOW AHEAD 2-FULL AHEAD
3-STOP 4-SLOW ASTERN

one-quarter, one-half, and one, times the full voltage specified for that motor (see Fig. 14.2). According to the position of the sequence switch, quarter, half, or full speed is available.

This would normally be incorporated with another sequence position which is blank—giving engine stopped—and with the possibility of another position reversing the polarity of the battery to give "engine astern."

Because of the ease with which an electric motor can be controlled by straightforward electrical switching the least requirement would normally be "ahead," "stop" and "astern," calling for three sequence positions on the switcher. Some electric motors designed as marine power units incorporate switching connections for "ahead" and "reverse" on the motor terminal itself (and when running in reverse may operate with a weaker field to give slower speed astern). The straightforward electric motor, however, must have the battery polarity reversed to run in the reverse direction.

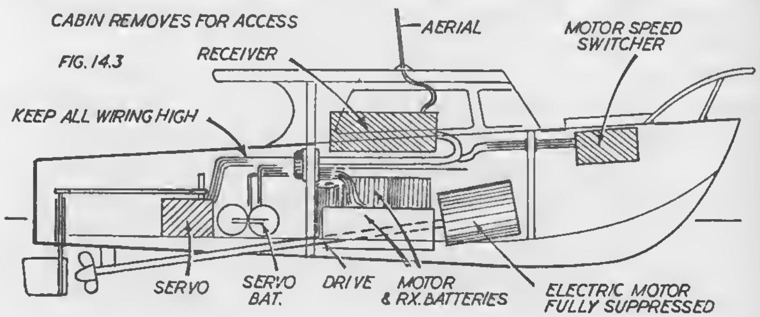
Figs. 14.3 and 14.4 show a typical simple single-channel system using a compound servo for selective signalling of rudder, self-neutralising on release of signal, with the "third" position or "quick blip" used to control a clockwork escapement providing changeover or sequence engine speed control (see Chapter 6 for details of "compound" servo action). An escapement is quite suitable for motor-speed control and the use of a clockwork type saves having to fit a rubber motor with the problem of having to locate it along the length of the hull and rewind it regularly. The clockwork escapement still needs regular rewinding, but this is conveniently done with a key.

Other types of "compound" servos may provide further services—i.e. to switch one or more additional escapements, each controlling a further service. These would normally consist of "novelty" services, like blowing a horn, lowering and raising the anchor, switching navigation lights on and off, etc.

An alternative method with single-channel operation is to use a sequence switcher, preferably operated off the "quick blip" action of a compound servo. This switcher then provides a sequence of switching positions closing auxiliary circuits, in turn, like Fig. 14.2. The servo "third position" switching is then still available as a separate selective control for operating motor speed. The switcher is merely a simple method of multiplying the potential duties of the compound servo. Because none of these additional services is critical—and none has to be

selected rapidly—it is possible with a little ingenuity to adapt the "quick blip" switching on the transmitter to operate via a telephone dial. Instead of having to remember the sequence (number of quick blips required to select a particular service following the *last* service used on the switcher), the required service can be dialled by number.

Multi-channel offers the advantage of *direct* selection of a particular control service but the number of channels required for complete functional control is considerably less than with aircraft. Three channels will give direct rudder control and changeover engine speed. Four channels will give rudder and full-range throttle control (with diesels or glow motors).



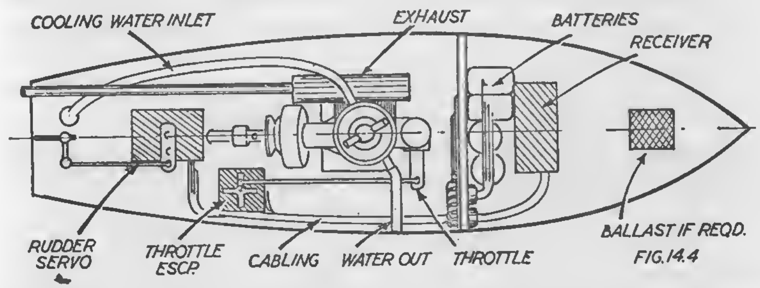
Further channels are a luxury although one additional channel to use for sequence selection of non-critical auxiliary services is attractive.

The separate channels available with "multi" can, of course, also be "compounded," if desired. Thus one channel could be used to operate a compound servo for selective switching of rudder and motor speed, and the other channel another compound servo for selective switching of three or four more services. This is the equivalent in scope of having two single-channel receivers in the boat. Three-channel radio could be "separated" as the equivalent of *three* single-channel receivers, and so on, not that there is any advantage in having a multiplicity of control services if positive and immediate switching of the main rudder control becomes more difficult, or liable to error.

With high-speed craft, multi-channel radio can be a distinct advantage for *direct* selection of the *functional* controls on which

the behaviour and safety of the model depends—rudder and motor speed. The more moderate the performance, however, the more attractive it becomes to add additional services. The thrill is then not so much controlling a boat travelling at high speed as in devising and getting to work a number of auxiliary services so that the boat behaves as if "crewed"—and can dip her flag in salute to a sister craft, if called for! Some modellers will prefer to go after performance; others will find more satisfaction in striving for the realism of "everything working" under remote control.

Proportional controls are also suitable for boats and work on similar principles to aircraft systems (see Chapter 8). A pulsed single-channel transmitter signal operating a proportional-type



actuator will produce a somewhat smoother action on a boat rudder than on an aircraft because of the damping action of the water load, and is all that is required. A motor-speed changeover actuator can be operated off an extreme control position to cover all the main functional control requirements. The dual-proportional system (see Chapter 11) could, of course, be applied to the rudder and full-throttle-range motor speed.

Installation problems are seldom severe with a model boat, for weight is not critical and there is generally plenty of room to spare in the hull to accommodate the necessary equipment. Weight distribution is important in so far as it can affect the trim of the model in the water and so positions should be selected for the main weights, such as batteries, consistent with proper trim.

As general recommendations, the receiver should be placed forward in what is usually the "dryest" part of the boat: the **steering servo** should be located close to the rudder (and the

motor-speed actuator reasonably close to the motor) so as to reduce the length of linkage required; and particular care taken with diesel or glow-motor installations to lead the exhaust-waste off through a pipe so that the interior of the hull cannot get fouled. These are not invariable rules. In some hulls it may be more convenient to group receiver, servo and batteries together in one part, even if this does require a long mechanical linkage to the rudder. In all cases, however, where a "dirty" power plant is used, such as a diesel or glow-motor, or steam engine, locating the radio and electronic gear *forward* of the power unit is usually the best method of protecting it against oil, etc.

In the case of an electric-powered boat it is usually an advantage to mount the receiver as far from the electric-drive motor as possible to minimise the chance of interference. The

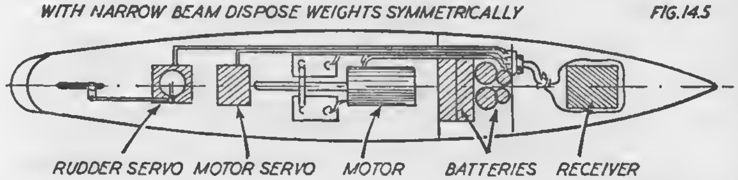


FIG. 14.5

drive motor would have to be suppressed, in any case, but complete suppression may not be possible as there is still a chance of stray radiation from the internal leads of the motor. Moving the receiver as far away as possible is simply a common-sense precaution.

Some typical layouts are shown in Figs. 14.3, 14.4 and 14.5. In nearly all cases there is usually a fair length of fore and aft run of cabling. A vertical aerial is therefore to be preferred, but not necessarily essential. The same considerations for suppressing "noise" apply as with aircraft and if bonding is used can conveniently be "earthed" by further connection to the stern tube. All wiring should be kept neat and tied together in the form of cables, rather than left to lie loose in the bottom of the hull.

Vibration is usually far less of a problem than with aircraft. With electric power there should be a complete absence of vibration. A diesel or glow motor with flywheel usually vibrates less than the same engine driving an airscrew but

with this form of power unit it is still advisable to shock-mount the receiver on foam rubber.

The greatest enemy of the radio gear will be dampness. Although it is unlikely that the receiver compartment will get flooded (except in an accident), there is always the possibility of dampness in the hull attacking the receiver. This is particularly the case with models operated in sea water where contacts, in particular, may rapidly become pitted by corrosion. The reed units of multi-channel receivers are particularly likely to suffer in this respect.

It is a good idea to protect the receiver against damp by enclosing in a polythene bag, making off the end of the bag around the leads and holding with a rubber band. This does not necessarily provide complete waterproof protection if the hull is submerged, but it should keep out most normal dampness. The only trouble is that access to the receiver tuning control is considerably restricted by the presence of the bag around the unit and it may be necessary to fit a small knob to the tuning control which can be operated through the bag. It is necessary to tune with the receiver finally fitted, and also with the craft in the water. To be correct, too, the aerial wire should emerge from the bag at a point separate from the main wires carrying the receiver and servo currents.

On many craft it becomes a problem to accommodate the recommended length of aerial. A vertical aerial is best, but a wire sticking straight up does not always look right. Fortunately aerial length is not usually all that important for the range required is fairly low. A horizontal aerial inside the hull will often work quite satisfactorily, or one led fore and aft above deck. With horizontal aerials care should be taken to ensure that the free end cannot lie in moisture (e.g. water in the bilges, or moisture on deck, and so effectively earth that end of the aerial.

Remember, too, that moisture attack is not confined to the receiver. It can affect the servo just as much and the compound servo relies on a multiplicity of wiping contacts for its action. Dirty or high-resistance contacts are the most common cause of failure. Dampness in electric motors can lead to loss of performance, excessive arcing and general deterioration. Contamination of switches and contacts with spilt fuel (which

invariably contains oil) or exhaust waste can also lead to trouble. Although model boats are not subject to the same "operational" hazards as model aircraft their environment is generally less favourable.

Yet another field of R/C application to boats is the remote control of steering, etc., on model yachts. For steering the requirements are basically the same as for power boats, with a servo preferred to an escapement. Only a simple servo is required for there is no immediate application for further switching positions.

Where radio control is extended to handling the sheets as well *direct* control is generally preferable, calling for multi-channel equipment. The use of servo-motors as winches for controlling the length of the sheets, however, is debatable in practice as there is always a possibility of these fouling or jamming unless some form of spring tensioning is given to the sheets all the time. Similarly, aircraft-type servos are not necessarily suitable for this type of work on account of their limited travel.

The best scheme is normally to employ one servo for sheet handling with a lever movement, to which both jib and mainsail sheets are attached (and thus controlled). The necessary differential movement can then be obtained by the use of blocks to multiply the free movement of the mainsheet, and alternative attachment points on the servo arm. Bias will also be required on the main boom to ensure that it moves to take up any alteration in sheet length (particularly in light winds) (see Fig. 14.6).

A practical installation on the lines of Fig. 14.6 would be group receiver, batteries and both servos in one integral unit or box which can readily be installed and lifted out, with quick-release attachments to the respective servo arms.

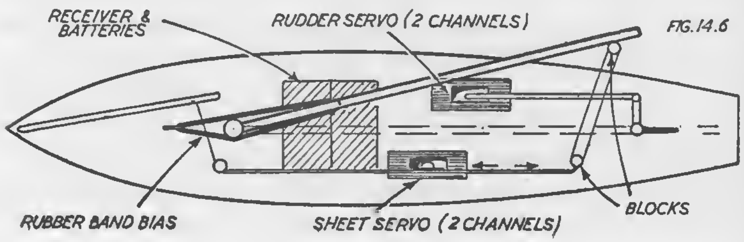


TABLE III. R/C YACHT CONTROLS

Radio Equipment	Rudder	Sheet Setting Jib *Plus* Mainsail	
Single-Channel	Simple S-N Servo	No	
	Compound S-N Servo*	No	
Single-Channel (proportional)	Proportional Servo	No	
Multi-Channel 3-Channel	"Bang-bang" or Progressive*	Linked to progressive servo	
4-Channel	"Bang-bang" or Progressive*	Progressive (both directions)	
6-Channel	"Bang-bang" or Progressive*	Progressive Servo	Progressive Servo

*Preferred.

CHAPTER 15

R/C LAND VEHICLE MODELS

THE radio-controlled model land vehicle is very much a "one-off" job. Unlike model aircraft and model power-boats where numerous kits and designs are produced specifically for radio-control application, the radio-controlled car, truck, etc., is usually a model produced for its novelty value, or appeal, by an individual modeller. Thus it is impossible to describe general practice in this particular field. However, only standard radio-control gear is required, as described in previous chapters, and there are certain specific requirements to be met.

The land vehicle is like a boat in requiring a minimum of functional control services. It is also subject to a similar "time delay" in responding to control movement—unless a high-speed vehicle is contemplated—so that selective sequence switching will be satisfactory. However, a "bang-bang" type actuator is far from the ideal for a steering control and so the logical choice for this function is progressive control, or proportional. The former *can* be operated off single channel since absence of a neutral position is not critical, but would be best operated off two channels of a multi-channel system. An electric motor is the logical power unit for this class of model, when "forward," stop and "reverse" speeds would provide a complete control system.

The question of weight and balance is not important in a vehicle and so the components can be arranged where most convenient within the volume available. Here there are two possible starting points—adapting an existing model which is large enough to accommodate radio gear; or building the model from scratch and proportioning it to accommodate the gear to be carried. In the former case space available is pre-determined and must, to a large extent, govern the choice of components, as well as positioning. Fig. 15.1 shows the layout of a complete system installed in a 1/24th scale plastic model car.

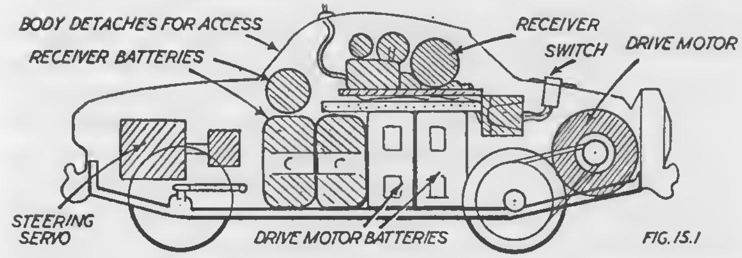


FIG. 15.1

Virtually all the available volume is used up, calling for no little ingenuity in layout. If it were simply a case of building a model around a particular control system then it is only necessary to lay out the components on a suitable base (forming the effective chassis of the vehicle) and design and fit a suitable body. A van body, for example, would be a logical choice to accommodate maximum volume with a minimum chassis size, and also be the easiest to make.

A basic layout plan is shown in Fig. 15.2. As far as possible it is desirable to locate the steering actuator near the front wheels for minimum length of linkage; and the drive motor near the back wheels. The remainder of the space is then available for locating batteries and receiver, and any secondary actuators.

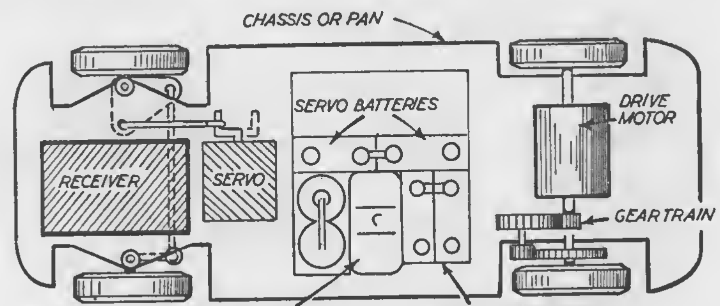


FIG. 15.2

A *servo* is essential for operating the steering mechanism. An escapement will not have enough power. A secondary actuator could, however, well be a clockwork escapement for switching the motor-speed control.

The simplest single-channel system would utilise a conventional compound servo, and thus sacrifice ideal steering

for "bang-bang" movement. The "third position" or "quick blip" on the compound actuator would then be available for sequence switching via a secondary actuator to control motor speed—forward, stop and reverse. Alternatively one of the more sophisticated types of single-channel compound servos could be used which provide sequence-switching positions capable of controlling the necessary motor circuit directly. The ingenious modeller would make or adapt a suitable compound servo to give these characteristics.

A simple "progressive" steering action is shown in Fig. 15.3, where the servo is an ordinary electric motor which, when energised, drives continuously to turn the steering from full-lock one side to the other and back again, continuously. Assuming that the motor circuit is controlled by a relay the geometric position of the steering at any time depends on where it stopped when the last signal was released. The next signal will cause it to move in the same direction, then back again. Thus from any given steering position to start with and new position can be taken up by timing the duration of the next signal.

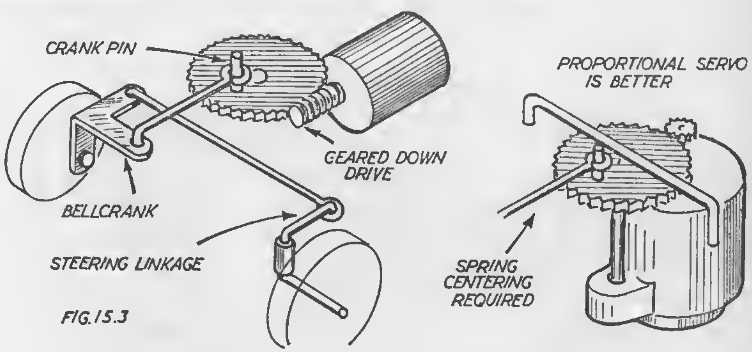


FIG. 15.3

It is necessary to gear the motor drive down so that the actual rate of steering movement is fairly slow, when "position" can be judged by effect—i.e. which way the model is turning, and the turning radius. It is not a very practical system to operate, however, even with considerable practice. It also suffers from the fact that to turn, say, to the right *following* a right turn which has been taken off it is necessary to steer through full "left" first before travelling back to "right."

It is one of those simple systems which can be a lot of fun to try out on a simple chassis mock-up—but not good enough to build a complete model around.

Proportional steering control is distinctly better, using a pulsed single-channel signal, provided the steering load is not too heavy for the proportional actuator to handle. It is probably the most effective of the simple control systems but necessitates using largely "home-made" equipment for the transmitter pulser and the proportional actuator. The pulse mark : space control at the transmitter can conveniently be operated by a knob simulating a steering-wheel, so such a system is particularly easy to control (see Chapter 8 for information on additional controls available from "pulsed-proportional" systems).

A multi-channel system is shown in Fig. 15.4. Here the multi-servo is connected to operate progressively so there is no self-centring action. However, since "right" or "left" turn can be signalled at will there should be no trouble in obtaining synchronisation of "demand" with "signal" after a little practice. If a sequence switcher is used with a third channel then the necessary three steps in motor speed control also become available, operated by three-channel equipment. This, basically, is about the simplest and most reliable *complete* system.

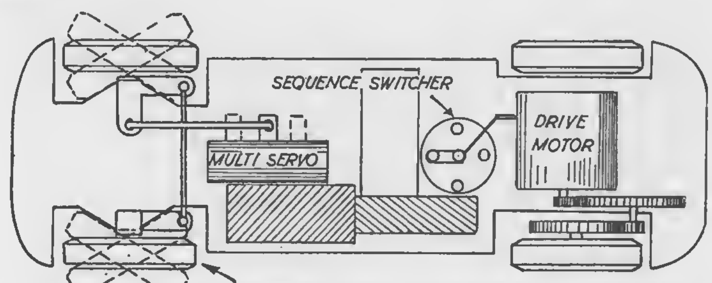


FIG. 15.4

One interesting point regarding the control of land vehicles. Since "left" and "right" are reversed, in visual effect, depending on whether the model is travelling towards or away from the operator, it is initially quite common to steer the "wrong" way whenever the vehicle is approaching. Exactly the same effect

occurs with aircraft or boat models, of course, but since the main attraction of a land vehicle is for more complex steering control it seems more common to make "pilot errors" with the latter where there is far less space available for manœuvring.

CHAPTER 16

OPERATION

It is an inescapable fact that the majority of radio-control "faults" occur because equipment was never thoroughly checked and adjusted, if necessary, *before* attempting to fly or operate the model. Particularly in the case of aircraft—where radio failure can be disastrous—a model should *never* be flown unless all the controls check out as working satisfactorily and reliably. Symptoms of "skipping" actuators or some other incipient fault will not "come right" in the air. Almost invariably the reverse is true.

Checking starts right with installation. The radio-control system will only be as good as its wiring, and particularly wire joints. All connections, including those to batteries, should always be soldered unless suitable plug connections are available. It is also important to check wiring installations completely through, wire by wire, before switching on for the first time. Even the most expert electronic engineer makes occasional mistakes in wiring. The amateur is likely to make a good many more. Check *before* plugging in the batteries that the wiring *is* correct and according to instructions or plan, as wrong connections could cause damage to the receiver. All commercial equipment is normally supplied with complete wiring instructions (where applicable). Different manufacturers do not, however, necessarily use the same *colour code* for wires performing a similar duty (e.g. battery connections)—hence the necessity of following manufacturer's instructions.

Tuning of the receiver to the transmitter is generally straightforward with modern equipment. Again explicit directions are normally supplied with the equipment. Other information on this subject will be found in Chapters 2, 3 and 4.

Certain precautions must, however, be observed in tuning. The tuning control normally provides for adjustment with a screwdriver. It is essential that the tool used must be non-

metallic (otherwise its proximity to the component would temporarily affect its behaviour). Any insulating material will do, like a plastic knitting needle or Perspex or Paxolin rod sharpened to a "chisel" end. Some tuning slugs have a hexagonal hole for the tuning tool for which plastic tuning wands are available to fit. A metal Allen key must *not* be used in such cases.

Initial tuning, for convenience, is best done with the transmitter and receiver fairly close together, but not too close as otherwise the signal may "swamp" the receiver and make it impossible to tune. Transmitter output, for initial or close-range tuning, is usually reduced by retracting the aerial. Tuning, basically, then consists of finding the *range* of movement of the tuning control over which the receiver responds to the transmitter signal—i.e. from one position to the other where the signal is "lost" in each case—and then finally setting the tuning adjustment in the *middle* of this range as representing the optimum tuning position.

Where a simple single-channel CW receiver is involved, a meter can be inserted in the receiver circuit (usually in one HT battery lead) and tuning adjusted to give maximum (or minimum) current reading, as specified for the particular set. This, again, is simply establishing the "optimum" position. With most modern equipment it is just as accurate to work on response—i.e. the range of working of the actuator connected to the receiver—and establish the middle position, as above. With some types of equipment this is the *only* method of tuning readily available.

With a single-channel tone receiver tuning may also be done with headphones. Suitable tapping points for the phones will be indicated on the circuit diagram or provided for on the cable plug. With the receiver switched on but transmitter off, a characteristic hiss will be heard in the phones, indicating that the super-regenerative circuit is oscillating correctly. With the transmitter signal "on" the receiver is tuned until the hiss stops. The tuning control is then turned further one way until the hissing starts again; then back in the other direction to the extreme point where hissing is heard again. The middle position between these two settings establishes the optimum tuning point.

A meter can be used instead of phones. The meter will show a nominal idling current which will drop on receipt of carrier signal. The receiver is then tuned for minimum idling current with the transmitter carrier on; and finally it is checked that when the "tone" is keyed the receiver current rises to the specified value (see also Chapter 4).

The use of phones in the circuit, incidentally, can be extended to listening for "noise" generated by actuator linkage, etc. It is often quite surprising the amount of "scratching" noise that occurs on operating a control. If bad, the source should be traced and the cause rectified (e.g. by bonding).

Tuning *must* then be re-checked at range, this time with the transmitter aerial fully extended and the transmitter in the normal position it will assume in use—e.g. held in the hand, or ground-standing. The model should also be held about shoulder high (if an aircraft). If a boat, final tuning *must* be done with the boat in water. Tuning procedure is exactly as before except that this time it will be found that the range of movement of the tuning control to stay "in tune" will be appreciably reduced. Also the central position may be somewhat different from that found by initial tuning.

The distance at which the range-check is carried out is largely arbitrary. A 200-yard range is generally adequate for aircraft, with less for boats (see Chapter 14). It is important that a range-check *is* carried out, however.

Just how frequently tuning needs to be checked in future depends very much on the stability of the transmitter and receiver—and also whether either may have received mechanical damage or severe shock. Given good quality equipment it is usually satisfactory to repeat a brief short-range check *before every flight.* If after the initial range check tuning the *extreme range* given when the transmitter aerial is retracted is found, future checks at just short of this range (again with transmitter aerial retracted) will confirm that tuning is in order. If this (aerial retracted) range is found to be drastically reduced, then re-tuning is probably called for.

Although properly tuned, the equipment is not necessarily workable until checked for control operation with the motor running. Motor vibration may upset escapement operation

or cause the relay armature or reeds to chatter. "Noise" may also show up at a sufficient level to cause interference. Faults such as these are nothing to do with tuning (unless the receiver has a sensitivity control adjusted to too high a level of sensitivity), but must be traced and eliminated from the circuit. Note particularly details of arc suppression and electric motor interference suppression in Chapter 13.

A common cause of lack of range and/or sticky actuator action is low battery voltages, particularly when small sizes of dry batteries are used. In a majority of cases low tension dry batteries (and particularly those used as actuator batteries) are subject to current drains far in excess of their nominal rating. As a result they polarise rapidly and quickly lose voltage.

All battery voltages *must* be checked on load, i.e. when in the circuit and switched on. It is quite meaningless to measure the voltage of a battery simply by putting a voltmeter across its terminals. Battery voltage on load should be measured when the circuit has been switched on for a minute or so (in the case of receiver and transmitter batteries); or during the operation of an actuator (in the case of actuator batteries).

Receiver and transmitter batteries have a nominal end-point voltage below which satisfactory performance will not be given. This does not mean that they can be used right up to this point. Range will decrease all the time with falling voltage and when the battery approaches its nominal end point it will be quite substantially polarised and likely to suffer a further voltage drop quite rapidly. As a general rule no dry battery should be used after its "on load" voltage has dropped to 0·8 times the voltage it showed when new and fresh.

Do not overlook the fact that low *transmitter* batteries can be just as much a cause of lack of range as the receiver batteries. Receiver batteries are normally regarded as the "weak link," largely because they are of the smallest practical size to save weight and bulk. The current drain on hand-held transmitter batteries is quite high, however, and they need frequent checking.

Battery troubles are largely eliminated by using accumulators instead of dry cells—DEAC cells being particularly favoured. It is not practical to use high-voltage batteries of this type. However, fully-transistorised receivers operated at

voltages well within the range of practical DEAC accumulator weights and sizes. The use of a power-pack also enables low-voltage accumulators to be used for high-tension supply in a valve circuit (see Chapter 2). A power-pack operated off a single DEAC accumulator can provide the complete supply for the receiver and actuators. Similarly, a power-pack can also be used for providing transmitter HT and LT supply. Apart from more reliable operation the great advantage of accumulator-type batteries is that they are re-chargeable and thus can be kept topped up and always at full strength when required.

Fault-finding is not a subject which lends itself to general description. Many faults which can develop are characteristic of a particular receiver or actuator—or even the transmitter. Others may be specific to installation. The most common "electronic" fault is low batteries—followed by dirty contacts. Provided the equipment is correctly set up and adjusted initially these are the most likely "electronic" troubles—short of mechanical damage following a crash or component failure. The latter usually requires expert knowledge to check and rectify—or the return of commercial equipment to the manufacturer for service.

Contacts on relays and reeds can get dirty and require cleaning. A more common source of "dirty" contacts, however, is burning or pitting due to their being called upon to pass too heavy a current. This can occur if contacts are not fitted with arc suppression, or if the actuator controlled by the contact is operated on too high a voltage, deliberately chosen to get a more powerful "action."

Mechanical faults are generally easy to trace—but not always easy to cure. Vibration is an inherent characteristic of a single-cylinder two-stroke engine, however "balanced" it purports to be. There just is no such thing as a balanced, vibrationless single-cylinder engine. Some engines do, however, vibrate much less than others. Glow motors are usually very much better than diesels in this respect, which is one reason why they are more favoured for radio-controlled model aircraft.

A common source of excess vibration, however, is an unbalanced propeller. Since this is normally rotating at speeds in excess of 10,000 r.p.m., any slight unbalance will show up

strongly. Balancing is quite easy to carry out and well worthwhile. Another method of minimising engine vibration is to find the best *attitude* for tightening the propeller on the engine. In some positions it may produce heavy engine vibration and in another minimum vibration. The disadvantage of this method is that it does not always leave the propeller in a suitable position for hand starting.

Other mechanical troubles which may arise are sticking control linkages—either due to poor design and installation, or possibly as a result of crash damage; or excessive vibration or free movement due to wear on hinges or bellcranks. These, like structural damage, represent normal "model maintenance" and should be dealt with as soon as the trouble shows up. It is more important to keep a radio-controlled model in first-class condition, regularly serviced, than its free-flight (or free-running) counterpart. It carries an expensive investment in time and money in its control gear. In checking the radio side at frequent intervals it is equally important to appreciate that the *model* also may require regular servicing.

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